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TABLE OF CONTENTS.

Some Suggestions Concerning Strikes....Frank L. McVey 1
Engineering in South America.....W. C. Weeks 8
Chemistry as an Elective for Engineers.....F. F. Sharpless 17
A Novel Three-Phase Alternator.....Geo. D. Shepardson 26
Inspection—Its Place in Modern Engineering..A. C. Beyer 30
The Heat Treatment of Iron and Steel.....Harry E. Smith 37
Improvements in the Three-Wire System..Truman Hibbard 45
Recent Railway Economies.....E. E. Woodman 58
A Multifunctional Dynamo.....Geo. D. Shepardson 74
The Modern Explosion Engine.....E. S. Savage 79
The Structural Laboratory.....Frank H. Constant 86
The New Dam at Minneapolis.....H. M. F. Dahl 93
Recent Railway Economies.....E. E. Woodman 58
Copper Minerals in Hematite Ore..J. H. Eby, C. P. Berkey 108
The New Distributing Reservoir.....C. H. Kendall 118
A Convenient Ammeter Plugboard....Geo. D. Shepardson 124
The Science of Photography.....H. C. Hamilton 128
A Cut-Off for Steam Compression.....Dr. Henry T. Eddy 136
The Gillette-Herzog Competition..... 138
Editorial 140
Obituary 142
Members of the Society of Engineers and Alumni..... 143

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OF THE

SOCIETY OF ENGINEERS.

MAY, 1897.

SOME SUGGESTIONS CONCERNING STRIKES.

FRANK L. McVEY, Ph. D.

When the average man looks at some great building towering many stories above him, or crosses a river on an ingenious arrangement called a bridge, he is likely to consider these structures as the products of the brain of an engineer or an architect. The work and labor behind the engineer and architect are forgotten in his admiration. Possibly even the contractor is overlooked, while the hundreds of men whose daily toil has made the accomplishment of the plans possible are not given a thought. The last two factors are largely neglected in our technical and mechanical education. The problems which arise from association with contractors are being met in some degree, in our technical schools, by law lectures on contracts; but very seldom is any attention paid to the constantly increasing difficulties of labor employment. And in that human labor is a great essential in engineering enterprises the young engineer is far from being equipped for his work unless he understands something of labor organizations, their purpose, and methods of work; and still more, knows what human nature is in all its phases. The first he can get by study and observation; the second can be acquired if the young engineer has a native ability for leading and understanding men.

Recognizing this as a valuable opportunity to present to engineers the necessity of understanding industrial conditions, the writer has readily undertaken to say something about the great labor problem, i. e., strikes. In the limited space assigned it will be his intention to show the dangerous and expensive character of strikes, the reason for their existence, the elements which make them difficult to deal with, and, finally, some general suggestions as to the treatment of men with grievances.

A strike can be defined as an attempt on the part of employees to secure higher wages or a settlement of a grievance by quitting work.

In the beginning of this century strikes were a necessity in England. The laboring class at that time was largely destitute of political franchise. As a class they were burdened with taxes and were uneducated. Society, at the same time, had a fixed way of considering the laborer, regarding him as a kind of machine without human sympathies and wants. There was need in consequence, of a series of fierce revolts that would break up the customary and established ways of looking at the workingman. And it was only by means of the revolts that he was able to secure new liberties. The damage done was small in comparison to the good accomplished. The competition between manufacturers at the time was limited by lack of communication and facilities for transportation, so that the effect of such an insurrection was confined to the locality in which it took place.

All of this is changed at the present time. The influence of a great strike is now felt almost everywhere. Railroad traffic is stopped and the supplies which are necessary to the existence of people are held back. Society is so highly organized that a blow at one part is transmitted to every other part. Both the public and the contestants have found this to be true. The expense of such a strike to those immediately concerned seldom justifies the results, and the disastrous effect on the general welfare of society can hardly be estimated. Under these circumstances we should look for a decrease in the number of strikes; but this has not been the case. In the year 1881 there were 471 strikes, involving 2,928 establishments, causing 130,000 to be thrown out of employment. In 1894 there were 896 strikes, involving 5,154 establishments; 482,066 men were thrown out of employment in consequence thereof. During the period between the years just mentioned

14,389 strikes occurred. Some 69,166 establishments were involved and 3,700,000 men were made idle. One-half of these strikes occurred in the last five years of the period mentioned and involved 32,780 establishments and caused 1,600,000 men to be thrown out of employment. Naturally enough the greater number of these strikes occurred in the larger cities. From June, 1887, to June 30, 1894, there were 5,909 strikes in the cities of the United States, 2,614 happening in New York City alone.

The statistics given above do not tell one-half the story. The loss in wages to employees from strikes and lockouts in the period 1881 to 1894 amounts to $190,493,173. The employers, on their part, have lost from the same causes $94,825,000. In addition to these sums the labor organizations advanced $13,438,000 to help carry on the conflict. The loss to all immediately concerned is the grand total of $298,756,000. Nor does this sum of nearly three hundred millions include the indirect injury to society. In order to get complete returns it would be necessary to know the damage done to business of all kinds by delays in shipments, increased rates of insurance and the thousand and one inconveniences and privations which third parties have been occasioned. Just what sum of money could be said to cover this loss to the entire country is difficult to say, but it certainly is very large. It all goes to demonstrate the fact however, that this method of settling differences is expensive and unjustifiable.

The causes which occasion these industrial conflicts are not seen in their full importance at first glance. The one which appears most prominent is the failure on the part of both employer and employee to understand their mutual relation and interest. This cause can be separated into arbitrary acts of employers, refusals to hear grievances, and the constant misunderstandings concerning wages, time and discharges. There are other causes, such as false economic theories, like the following: Profits fall when wages rise; limited numbers mean higher wages; and reduced products will increase piece prices. As a general thing strikes are caused by misunderstandings. This is due to the refusal of one side or the other to explain the situation. Then follows a pitched battle, lasting an indefinite period, in which the public is compelled to take one side. The employer sends out circulars warning other employers against certain laborers, and setting forth the cause of the trouble from his standpoint. The

strikers do the same, only giving a much broader circulation to their manifesto. Possibly the strike spreads to other industries, simply because there has been no intelligent effort to get at the cause of the trouble in the beginning.

A further analysis of causes enables us to group them as follows: (1) Wages, (2) hours of labor, (3) men to be employed (often nothing more than a mere discrimination between union and non-union men), and (4) sympathetic strikes. Of the 46,862 establishments that were connected with strikes or lockouts in the period January 1, 1887, to June 30, 1894, forty-three per cent or 20,394 of them had trouble over the question of wages. Some 6,199 were disturbed by the single question of hours of labor, and 3,095 over a combination of the questions of wages and time. Reduced to a percentage, we may say that 13 per cent of the total number of establishments were engaged in strikes because of attempts to increase or reduce the time of a working day. Under the third group of causes 5,090 establishments or 11 per cent, in the same period, were engaged in strikes over the employment or discharge of men. There were 3,620 establishments, or 7.75 per cent of all the concerns, dragged into strikes because of the sympathy of the employees with strikes elsewhere. Besides the causes mentioned there were minor ones which involved such a small number of employers and employees that it is not worth while considering them in a short article of this character.

The principals in a strike can, for simplicity's sake, be confined to employer and employee. Both of these are influenced by outside forces. The position of the employee cannot be understood without a thorough consideration of his trade union relations, and the policy and leaders of the union to which he belongs. In his turn the employer cannot be separated from his business, his success in it, his policy of treating his men and the attitude of the public toward enterprise. In examining the case of the laborer we find that in the act of selling his commodity he seldom comes in contact with the buyer. He (the laborer) is nothing else than the object whose use he sells. The purchaser takes possession of the employee's person and controls it during certain hours of the day. The purchaser thus determines residence, place of working and employment of time. Naturally, combinations of workingmen followed in an endeavor to modify these conditions

to at least some degree. Hence the trade union is always an element to be considered in a strike. In this connection, however, it must not be thought that trade unions were established for the purpose of striking, for such is not the case. It is true that the union of laborers is a combination of employees to meet the employer, but that combination is the result of the factory system. The first and primary object of such an organization is to benefit its members generally in connection with some insurance plan. But being so organized, the union becomes a factor in strike troubles.

The policy of a union is too often opposed to reason. The members are blinded by prejudice in many instances and fail to see the results which would follow from their course. The reason for such policy on their part is largely due to the fact that it is guided in many cases by the man who can talk the loudest and frame the best sounding phrases about the tyranny of capital and the corruption of government. The conservative thinking man, and there are many in the labor organizations, is silenced and his counsel refused. Many mistakes naturally follow. If the union holds together under the pressure of the burden it has brought upon itself by listening to unwise counsel, the future actions of that union are apt to be guided by reason, and because of this to be an aid rather than a hindrance to the employer.

On the other hand the employer is by no means free from responsibility. The old relation of man to man before the growth of corporations has been superseded by the manager representing a corporation whose stockholders want dividends. In this connection the workingman becomes a tool that can be laid aside when necessary. When this is done no explanation is offered. The employees are forced to take up their own case in self-defense, refusing to accept the kindly offices of a third party for fear that the decision would not be accepted by the employer unless favorable to him. In all probability there are good reasons for the action of the employer in laying off men; but he refuses to make them public because his competitors in the same line of business may come to know his condition. But such a view is a false one, as the men are sure to accept a reasonable explanation, and the advantage to the competitor is small in comparison to the good will of the men. A refusal to explain, on the other hand, is regarded as a "causa belli."

There is another consideration. The business man of to-day is a money maker. That is his sole object and nothing is allowed to stand in his way. Sentiment and conscience are laid aside, for he finds he cannot afford to consult them. With him it is a question of success. His standing in the community depends very largely upon his ability to acquire wealth. So long as he can maintain such a position the public receives him with open arms. There is, in consequence, a temptation to drive hard bargains with employees and to take advantage of their necessities in order to maintain this position. The public overlooks the means and only regards the end as worthy of attention. Strike conditions prevail, therefore, without any restraint from the public which is deeply interested in the maintenance of industrial peace. The principals in a strike have been pointed out as employer and employee. The responsibility for strikes is wider, and rests not alone upon the factors mentioned, but also upon a third, the public. If strikes can be avoided without interference by the public, a great advance will have been made toward the true relation that should exist between employer and employee. How trouble can be avoided, at least to some degree, will now be considered.

A strike is not a spontaneous thing. It takes place after much agitation and planning. A few men, more intelligent than the others, are always consulted in such an event. To know these men is the first duty of the young engineer. Unless he does become acquainted he can hardly understand their point of view in questions involving their rights and comforts. He must also avoid any tendency toward arbitrary actions, for men are quick to take offense at any inclination to be overbearing. In fact, they are to be considered as allies, not as mere hirelings. Nor is such talk mere theory. Firmness, coupled with consideration and kindness, will be a true preventative of strikes. In case trouble should arise every step should be taken to prevent misunderstanding and the development of hostile feelings. This can be brought about by asking the men to send a committee to meet the employer and his representatives for the purpose of talking over the situation. The one great object of such a meeting is to secure an understanding, and if possible, an agreement, to which both sides pledge their support. A spirit of concession and fair play will produce valuable results toward this object. If the trouble has not gone too far it is likely to be settled at once. Sometimes the trouble

may have advanced to such a stage that it is impossible to secure reconciliation; then the employer or his representatives should endeavor to secure a submittance of the case to some third person or persons, who are known to be upright and honorable. Although the decision rendered may not be entirely satisfactory, it is far more economical in the long run to abide by the decision than it is to undertake a long and expensive fight whose result is by no means certain.

In conclusion it can be said that the relation of men to employer and vice versa rests upon judgment and common sense. It is easy to start a quarrel which may develop into a strike. The young engineer may find in such an event that he has cost his employer far more than all of his mistakes in construction. The one way to avoid labor complications is to be firm, kind, just, and to act as good, hard common sense dictates.

ENGINEERING IN SOUTH AMERICA.

W. C. WEEKS, '94.
U. S. Assistant Engineer.

It is with considerable hesitation that I write under this heading in a technical publication, of my experiences during several months of last year while engaged in exploring a portion of the Orinoco Delta in the Republic of Venezuela. Owing to the peculiar character of the country and a lack of knowledge of

Starting on an Exploring Trip.

existing conditions, very little work of an engineering character was done, and it will be the object of this article to give the reader an outline of the trip, a description of the conditions under which engineering or surveying must be performed, and make a few suggestions as to the most feasible and economical methods of prosecuting a survey in the tropics.

The Orinoco Company, limited, has obtained from the Venezuelan government a ninety-nine year lease of a valuable tract of nearly ten million acres of mixed low and hilly country lying in and south of the Delta of the Orinoco. It was with a view of exploring this vast tract of practically virgin territory that our party of sixteen men, for the most part, residents of Minnesota, set sail from New York on the 5th of March, 1896, my connection with the party being in the capacity of engineer. Our route was the usual one taken by steamers plying between New York and Port of Spain, a city of about seventy thousand inhabitants, situated on the island of Trinidad, British West Indies. We were equipped with supplies and instruments for conducting a tour of exploration, including plenty of arms and ammunition, and a steam launch complete. Six days after starting we passed through the treacherous Boca de Dragos and dropped anchor in the harbor of Port of Spain. Here a delay of two weeks occurred, caused by the destruction of the hull of our launch during the process of unloading, and it was not until the 25th of March that we embarked on the Orinoco trader "Bolivar" for Cuidad Bolivar, whence all who enter Venezuela from the west must repair, in order to make their peace with the Venezuelan custom officers. Our route was across the Gulf of Paria, through the "Serpent's Mouth" and up the Macareo channel of the delta to Banancas, and thence by way of the Orinoco to Bolivar, making a few stops on the way for the delivery of mail—no one save the officials being permitted to land. Friday morning, March 27th, the boat was laid alongside the sandy bank of the river in front of the City of Bolivar, the thermometer registering 102° in the shade, and not a breath of air stirring. Cuidad Bolivar is situated on the south bank of the Orinoco river, in the state of Bolivar, 273 miles from the sea, and has a population estimated at 11,000 souls. The city is built on a side hill in the usual style of Spanish architecture, the large buildings being for the most part of heavy masonry, the roofs of red tiles and protected against rifle fire by an extension of the side walls. These roofs offer a very secure refuge to the inhabitants in times of trouble, for from their advantageous position they can command the streets with comparatively little danger to themselves. The dwelling houses of the poorer classes are made of pole frames, to which bamboo poles are lashed, and plastered with mud, the roof being thatched

with an incombustible palm leaf. This latter style of architecture prevails throughout the delta.

Two days were spent arranging our affairs and in trans-shipping our goods to a light draft, stern-wheel steamboat, and we re-embarked for the concession. The following night we stopped at the iron mines of Manoa, where an English company had for a short time been mining, or rather quarrying, iron ore. A delay of a day occurred here, after which we went back up the Orinoco to the Island of Poloma, opposite the mouth of the unknown Toro river. At this time the dangerous illness of one

River Bank—Manoa.

of our party made it imperative that he be returned to the hospital at Port of Spain with the least possible delay, and our goods were hastily placed on shore at a native's hut and the steamboat moved away. No communication with us was possible for at least two weeks, and in the meantime we were to make camp comfortable and push the exploration as the means at our command permitted.

The two great drawbacks to any extended exploration at this time were lack of boats and motive power. The machinery of our wrecked launch was being transferred to another hull at Port of Spain, and not until the completion of this reconstruction could we hope for any other motive power than by the usual means of oars and paddles—and the ability of a white man to wield a paddle is strictly limited on those lower Orinoco tributaries, winding about through the low, alluvial delta lands walled in by a mass of impenetrable tropical vegetation, through which not a breath of air percolates to relieve the intolerable heat. This vegetation extends down and into the water of the streams, making it difficult to land from a boat, and almost an impossibility to gain the shore from the hazardous position of a swimmer. No footing can be had on the banks except in well chosen places, and then considerable work with the machete is necessary. When once on the bank, the explorer is surrounded by a vegetation so dense that any idea of making a survey from the bank is at once abandoned.

Our party remained two weeks in camp on the Island of Polona. Tent flies were hung to keep off the rain that now fell daily, and we were protected in our cots and hammocks at night from innumerable flies and mosquitoes by the "toldetta," an absolute necessity with the tropical explorer. The air was hot, moist, and produced a feeling of lassitude quite difficult to overcome, and in no way contributing to the successful prosecution of our work. Several short excursions were made along watercourses, and our routes "surveyed" as well as might be under the circumstances. By utilizing the clearing in front of a native's hut and that made by ourselves for the camp, a base line of 300 feet showed a point on the opposite bank to be 1,700 feet away, and this was the initial point on the rough survey of the Toro. Our only available boat was a steel lifeboat, well made, and incapable of being sunk. A couple of ranges were established on shore leading across the river, and the direction of these ranges carefully determined by compass while standing on the bank. Then by testing these courses from the boat when on the river, the error due to the boat's influence on the needle was determined and allowed for on all courses so taken. Rifles and other articles which might of themselves disturb the direction of the needle were kept at a distance—the magnetic declination

was taken from a marine chart. Distances were all estimated, with the exception of our short base lines. Seated in the middle of a boat, crowded with men and piled high with camp equipage, covered with tarpaulins to protect it from the frequent showers; compass and book in one hand, pencil in the other, the notes were taken and sketches of important points made, while the attention of the observer was being continually taken from his work by the screaming of strange birds, the stealthy movements of monkeys and aligators, the snort of the water dog or

Changing Camp—Paloma.

splash of the iguana from his leafy perch. A condition of mind bordering on distraction was continually maintained by the laziness and deliberation of our native oarsmen, ever ready to stop rowing at the smallest excuse, and often without any excuse at all, and in utter disregard of the fact that at such times our progress entirely ceased.

These explorations showed the country south of the Orinoco

river to consist of dense forests growing from a sticky, alluvial soil near the margin of the river, changing into irregular savannahs further inland with occasional ridges running down from the broken mountainous country still further south. Walking in these savannahs is attended with great fatigue. The grass is high, strong and as fire never runs here, the last season's growth forms an unstable, insecure footing having a great tendency to entagle one's feet. The total absence of any protection from the fierce heat of the tropical sun and the torture of the "bete rouge" renders travel across these grassy seas anything but pleasant. These savannahs are inundated to a depth varying between two and ten feet from May to September of each year.

At a later date, further exploration along this river showed an abrupt step from the delta to a higher and mountainous country. The river descends from the high lands in a long series of cascades and rapids with vertical falls of six to eighty-four feet, this latter waterfall marking the end of our exploration along this river. After the first ten miles from the Orinoco, there was nothing to indicate that human beings had ever preceded us, and we were without doubt the first white men to gaze upon those splendid waterfalls which have for untold ages broken the stillness of the tropical forests with their thunder. These falls were surveyed, vertical distances measured by barometer, horizontal distances carefully paced wherever practicable and checked by numerous triangulations to stations marked by poles. As far as we penetrated, the rivers abounded with alligators, electric eels and dangerous stinging rays, and it was fortunate that none of our party ever received serious injury.

Two attempts were made to conduct an exploration by land and these were carried on much the same as a preliminary railway survey. The vast amount of physical labor necessary to clear a path along which a passage may be made can only be appreciated by one who has been in the tropics, and the progress of an exploring expedition by land is most exasperatingly slow. Considerable difficulty would be found in leaving permanent marks of a survey except possibly by means of reference trees. I never saw a dead tree or piece of rotten wood in the tropical forest, so quickly is the destruction completed. The Orinoco river has never been surveyed except for an occasional "running survey" by the officers of some ascending steamboat. Any attempt to

survey the delta portion after the manner of the Mississippi river commission would necessitate a great expenditure, for there are no roads or trails except the "canoe path" and no elevated points upon which to establish stations. Perhaps the most feasible method of surveying the river would be by transit and stadia, running a carefully checked stadia line along each bank with tall signal poles at long intervals upon which to check up. Azimuth could be carried along this line of signals by the usual means of triangulation, and certain of these triangulation stations located

Ceropias Sarcupana.

astronomically by means of sextant and horizon. The soundings could be located by transits in the usual way from those stations giving the best intersections. For near by soundings, a stadia board fixed rigidly in the bow of a boat and observed upon by a single transit would be found practicable. The season for the prosecution of this work would be from November to May, the low water season. It is then possible to obtain footing outside the line of dense vegetation, and the exposed sand bars

could be utilized for temporary stations. These could be referenced to living trees on the banks. Even at this season, the river and its multitude of canos varies from a thousand feet to five miles in width; hence the necessity of a line on each bank. A steam launch and canopied barge—the larger the better—would be indispensable, for it is utterly impracticable to camp on shore. Three or four fair sized covered rowboats, manned by acclimated oarsmen, would be necessary for the transportation of the transitmen and their assistants; the signal poles could well be set by the launch. No trouble would be experienced from the river's current for at this season it flows one way as much as the other. The tide is said to extend its influence a hundred miles above Bolivar and I have myself seen boats at anchor at that city with their bows pointing down stream. Only instruments of moderate power, inverting images and equipped with platinum wires should be used. The latter is essential, as in that hot, moist climate, spider lines soon become useless. The instruments should receive a most careful examination under precisely the same conditions in which they are to be used, before the survey begins, and reductions made by tables calculated from the results of this examination. Aside from the measurement of base lines for testing purposes, I would not advise the use of tape or chain at all as being far too costly. Stadia boards may be of unusual length and size, say twenty or twenty-five feet long and six inches wide, with proper stiffening. The characters should be large and distinct. The mean of a number of observations with varying positions of the stadia wires should be taken as the most probable distance between stations; a single reading for "point shots" would be sufficient. The atmosphere is remarkably steady considering its moist, heated condition, and in the morning and evening there is no inconvenience from heat waves. Sunshades for the instruments must be provided, for the heat of his direct rays is almost incredible and on the exposed sand bars is terrible to endure. Light rain might be expected each day, for the distinction between the dry and rainy seasons in the delta is not very marked. The temperature in the shade throughout the delta would rarely exceed ninety degrees, and the difference between the wet and dry bulb thermometers rarely more than one degree—this latter showing the excessive humidity of the atmosphere. Its effect is very marked on the unacclimated, and little

physical labor should be attempted by white men.

All surveying should cease in April, for this is the beginning of the rainy season, when the whole face of the country is changed. The sun is obscured by clouds, rain falls frequently in violent showers, and where a short time before the white sand bars glistened in the sun, now runs the mighty current ten to forty feet deep, the dark muddy waters rushing onward to the sea regardless of the tide. For miles inland the banks are inundated, and the alligators swim unimpeded over the grazing ground of a month ago. Fog fills the forest, moisture drips from the trees, the whole region is abandoned to birds and monkeys and presents a most gloomy spectacle. Not until September do the rains cease; then the sun shines, interrupted only by occasional showers; the rushing flood of three months subsides gradually, and by November the banks and bars once more appear and make it practicable for the surveyor on the Orinoco to proceed.

CHEMISTRY AS AN ELECTIVE FOR ENGINEERS.

F. F. SHARPLESS.

The proper selection of electives is one of the most difficult duties of the undergraduate; difficult, because so many are offered while so few can be taken, and because of the fact that the undergraduate is lacking in the one element essential for intelligent selection, namely, experience. It is owing to this lack of experience that few electives are offered to engineering students and that the greater part of their subjects are required. Sooner or later, nevertheless, the time does come when he has an opportunity for making some choice of studies, and, naturally, among other questions, asks himself whether chemistry shall be one of these studies, whether chemistry is a luxury or a necessity, so far as it concerns his future welfare. If he decides that it is a necessity, as he certainly should, he then asks himself what amount of time he can afford to devote to the subject.

The subject of chemistry, and the proper amount for engineers, has been the cause of many controversies in the technical journals, and in the faculty meetings of many colleges; controversies presenting two good sides and not always ending in perfect harmony of the views of the disputants. If professors, broad-minded and of ample experience, are unable to agree upon these points after years of observation, how much less able to decide must the student of engineering be in the comparative embryotic state of development in which he finds himself at the time the questions present themselves?

When the student knows the line of work that it will be his fortune to follow, the task of selecting subjects is not a difficult one. It is a very easy matter to pick out those studies that have a direct bearing on his work and easy to avoid wasting time on subjects irrelevant to the known line that he is to pursue.

Unfortunately, it will be found that a very small percentage of undergraduates have any definite plans for their future; they are studying mining, civil, mechanical or electrical engineering, expecting, of course, to obtain a position in one branch or the other soon after graduation. It is advisable for such students to obtain as broad an education as possible, thus preparing themselves for whatever positions may be offered, and avoid specializing until

after the character of their work has been definitely ascertained. It is to this class of students, seeking as broad an engineering education as can be obtained in four short years, that the following remarks are addressed:

The expediency of the required courses in chemistry as now given in the curriculum for engineering degrees can hardly be questioned. They are the result of careful study and experience and may well be considered, by the undergraduate, as essential portions of his course. Taking for granted, then, that the required courses are essential, the question naturally presenting itself to a young man after they have been finished is, "shall I take any of my electives in chemistry or are there other subjects that will be of more benefit to me?" This is a question demanding serious thought and due deliberation. There are numerous factors which must influence one in making a choice of electives, personal and impersonal factors that are so different in individual cases that it is impossible to treat them collectively.

In making a selection from electives one naturally chooses the courses that appeal to him as being valuable and interesting and omits those courses which are void of apparent benefit. Early associations frequently develop or warp the mind in one direction; one young man has grown up in an iron manufacturing town, a second has been the office boy of an hydraulic engineer, while a third has seen nothing of engineering except on the location of some small mine where his parents lived. Each of these students will probably make his choice of electives in different directions; each knows what subjects are of interest to him, because his early associations have developed in him certain lines of thought to the exclusion of others, and in making his selection of studies, he frequently selects unwisely, merely because of lack of rudimentary knowledge of the subjects that are offered him. It can be easily seen that the case of each student is largely a personal matter. No broad statements can be made to cover all engineering branches, therefore, rather than point out a path for the engineering student to follow, this article will suggest only some of the uses to which the engineer may put his chemical knowledge, and leave him the option of making his own selections of the courses offered.

To the chemical engineer but few suggestions are to be made. He should prepare himself for the endless variety of work that is to come under his supervision; he should carry out carefully

some one line of work, but it is not advisable to limit himself outside of this one line.

The experience of several years as a public analyst has shown the writer the great diversity of material coming to the hands of the chemical engineer. During a year scarcely two samples, with the exception of gold, silver and iron ores, will be similar or will be subjected to the same treatment; from the examination of horse shoes, grindstones or cement rocks, he may be called to work upon a patent medicine or shoe polish, or he may be subpoenaed as a witness in a poison case. So broad is the field of this subject that one can only say to a chemical engineer who is not specializing, take all the chemistry you can get and vary your work in chemistry as much as possible.

As little advice need be given to the metallurgical engineer as to the chemical. It is obvious that the problems submitted to this engineer will fall within two lines—chemical and mechanical. The range of subjects handled by the metallurgical engineer is generally narrow; he adheres very closely to one subject; one will follow the working of lead, another of copper, while others will adhere closely to the metallurgy of iron and steel, but few have the time or opportunity to follow more than one course. While the lines of work are narrow, the details are elaborate and require hard, unremitting study for their mastery. An ideal metallurgical engineer is Sir Henry Bessemer, whose work has been confined to the chemistry of steel and to the study of economical methods for carrying out on a commercial scale the results of his laboratory experiments. In other words, his chemical and mechanical knowledge have been a happy combination, and its value to mankind can scarcely be estimated. It is evident that two courses are open to the student of metallurgical engineering, namely; that of specializing and the broader course treating in a general way of all the metals. Which of these courses should have preference? Generally speaking, the broader one is to be preferred, even though the line of one's future work is known. For example, if one's future work is to be confined to steel works, the writer would still advise the general course for the undergraduate.

Before one has had actual practice in his profession, before he has served his time at the furnace, he is unable to carry on judicious experiments and original work with the comprehensive understanding that should accompany such courses.

The undergraduate, when pursuing special lines, will naturally be influenced by his instructor in the selection of work and methods of investigation, and in fact is not only influenced, but is entirely dependent upon him and helpless without his continued assistance. The graduate who returns to his college after he has worked at the furnace knows the lines that will particularly interest him, understands the nature of the information that he seeks, and makes the legitimate use of his professor, namely, in obtaining advice as to methods and means for securing certain results and information.

To the metallurgical engineer the suggestion to be made is, take all the chemistry you can relating to the metals, but unless you have some definite plan for the future do not specialize.

Closely allied to the work of the metallurgist is that of the mining engineer, but his field is broader; it is seldom confined to one particular line, as that of the metallurgist, but includes nearly all of the branches that may come under the subject of metallurgy, civil and mechanical engineering. One of our well-known mining engineers of this country says: "To be a modern mining engineer one must know everything—all the laws of nature and all the laws of the land." This is very nearly true and is particularly true in regard to the laws of chemistry. The mining engineer is very frequently called upon for solution of chemical problems identical to those of the metallurgist. He must be familiar with the ores of all the metals, with their properties and composition; he must know how they are reduced and brought into the form of the pure metal. When he undertakes the examination of a mining property and its ore he must be able to report on a satisfactory method of working the deposit and for treating the ore. This demands an intimate chemical knowledge of the ore, fuel, fluxes and reactions of reduction furnaces.

A science of which the mining engineer makes continual use is geology, and particularly chemical geology. He uses this in his study of the formation of ore deposits, their shape, character and probable extent. In short, the mining engineer uses chemistry constantly; he uses it for all those purposes that the metallurgist uses it, and it serves him continually as it does the civil and mechanical engineer, to whom, as will be shown presently, it is a most valuable assistant.

At first thought, one might suppose that the civil and

mechanical engineer might well dispense with chemistry, especially as an elective, if not from among their required studies. A close examination of the work that they do and the materials that they handle reveals the fact, however, that both are continually confronted by problems which, for their solution, require a knowledge of chemistry. Think for a moment of the frequency with which problems are presented to these engineers in which iron, steel and all classes of structural material enter as factors. A thorough knowledge of the metallurgy and chemistry of iron becomes a necessity as does also a knowledge of building stones, limes, mortars and cements.

It is customary for the engineer of any structural work to require that the material furnished shall fulfill certain physical requirements, and generally that it shall fulfill certain chemical requirements. The purpose for which any structure is used must be purely physical and it would seem natural that if the material fulfilled all physical requirements it would be unnecessary to burden the manufacturer with useless chemical requirements, but this is by no means the case. In the construction of a metal bridge, for example, the engineer may call for a metal of tensile strength and elasticity falling within certain limits, for material with certain minimum compression strength, etc., but he cannot call for material that will enable him to give an indefinite life to the structure. A metal fulfilling all of the physical requirements could be furnished and yet be entirely unsuited to the purpose for which it is intended. It must be remembered that the material is to be used for a structure carrying heavy or light loads, a structure that may be subjected to all variations in temperature, to continued vibrations and shocks, but above all, it is to stand for an indefinite time. If the time clause could be introduced so that the engineer could demand that at the end of 100 years the metals and materials used should possess the properties they had when the construction took place, then he could disregard the question of chemical composition. The engineer must strive to obtain material that will give the best physical tests to-day and will stand the ravages of time as long as possible. In order to obtain such proper material he may use the specifications of structures that have been standing for a number of years, or he may draw up new requirements based upon the present knowledge of the laws of chemistry. As a matter of fact, specifications are fre-

quently but mere copies of some structure built years ago which has worn well and given perfect satisfaction; and one might suppose that a duplication would, when used again, give perfect satisfaction, but the "rule of thumb" is no more applicable to engineering work than it is to the more common walks of life.

The progressive engineer must be alive to the discoveries that have recently been made in the properties of alloys and other structural material. He must be able to take advantage of the chemical knowledge that is daily being offered to him. If certain elements are now being used that will increase the strength of the metal and thus lighten members of the structure, the engineer should know that fact and take advantage of it. He must understand the effect of varying the percentage of carbon, silicon, phosphorus, nickel, etc., in the material he is using. When a new alloy of apparently particularly desirable qualities is produced he should be ready to examine and adapt it to his uses if applicable, or reject it if inapplicable.

In short, it is just as important that the engineer understand the capabilities of the elements as it is that he understand the capabilities of his mathematics.

Again, if chemical knowledge is lacking, the engineer may demand a material that it is impossible or impracticable to produce. Last year, specifications written for steel rails for one of the Northwestern railroads, on which manufacturers were asked to bid, called for a steel so low in phosphorus that the bids came in at $32.00 to $35.00 per ton when it was expected that they would run from $22.00 to $25.00. The rail ordered would have been an excellent one, but would have required a very low phosphorus ore to make it, also a special run of the blast furnace and steel mill, hence the high bids. The engineer who drew up those specifications simply did not realize that he was calling for something impracticable to produce.

And still further, the chemical and physical properties may both be met in steel or iron manufactured by different processes. For the tension members of a bridge, acid Bessemer or basic Bessemer, acid open hearth or basic open hearth, or wrought iron might be used. If specifications are written so that any two or more of these metals may be used, the engineer should understand sufficient of the metallurgy and chemistry of the metal that he may know which metal to select. The metal will be offered at

different figures and he must have sufficient knowledge of it to know whether the cheaper one will answer his purposes or whether he must use the more expensive.

Chemistry also plays an important part in the masonry of the structure. Of what material is the masonry to be built? Suppose it is decided to use stone, then the question arises as to the most suitable variety. The specifications require that the material to be used must have a certain crushing strength, and a number of stones from different localities and at different costs, which will fulfill the requirements, are offered. In order to make a proper selection it will be necessary that the engineer submit the samples to a careful physical and chemical analysis and thus ascertain whether or not decomposition will probably take place while standing in the structure, under water or above, and whether time will improve or deteriorate the rock. Then as to the mortar and cement that are to be used. It is known that if the best quality of Portland cement is used it will probably be all right; but one may not be justified in doing this when several other brands are to be obtained at one-half its cost. The selection must again turn upon the chemical and physical properties of the various brands and this necessitates that the engineer must himself understand their chemical properties.

Turning from structural engineering to railroad engineering, we find here also that the knowledge of chemistry is a most valuable assistant. If the railroad engineer confines himself to the rod and transit, the less time spent on chemistry the better, but if he is a progressive man he will strive for something more and just as soon as he is through with grades and curves, then chemical questions begin to confront him. Without any knowledge of chemistry he does not appreciate that he is dealing with chemical problems, but it cannot be said in this case that "where ignorance is bliss 'tis folly to be wise."

That the chemist can have anything to do with the movement of trains, carrying of passengers or freight, may at first seem strange, but, nevertheless, he does play an important part in obtaining the final result. The most forcible way of illustrating the value of chemical knowledge to a railroad engineer is by giving a list of some of the questions that the engineers of one of our railroads have referred to their chemist.

The valves of certain steam cylinders are wearing rapidly.

What is the cause and remedy?

The varnish on passenger coaches becomes dull very rapidly. Can this be remedied in any way?

Certain boilers are forming scale very rapidly. How may this be prevented?

The lubricating oil used on the road is costing as much as ever but is not giving the satisfaction formerly given. What is the matter?

It is noticed that tires on certain engines are wearing well while those on other engines must frequently be renewed. What is the difference between the metals giving good and giving poor results?

We are paying twenty-five cents per pound for a patent scale remover. What is its composition, and what should it cost?

Such questions might be continued indefinitely. It is not contended that the railroad engineer should be able to answer them; this can only be done by the close study of an experienced chemist; but it is contended that the railroad engineer should know enough about chemistry that he may know how and when to use it for the advancement of his interests. He should understand enough of the laws of chemistry to know that in certain cases a chemist can solve the problem, can turn failure to success, and loss into profit.

The electrical engineer is a physicist and a chemist. The science that treats of electricity brings together and holds inseparably the subjects heat, light, magnetism and chemistry, and a knowledge of one is incomplete or cannot be had without an understanding of its associates. The science of chemistry is one of the foundation stones of the science of electricity, indeed it is an inseparable part of that science. The actions of wet and dry cells and storage batteries are all based upon the laws of chemistry. One of the most important and fruitful fields of electrical engineering is in the line of electric smelting and refining; here again are found the two subjects so interlaced and dependent upon each other that unless the engineer is well informed on both sciences he is absolutely helpless.

The goal that many an electrician has been striving for during the past decade and is still striving for is the economical production of electricity direct from fuel. Some results have already been obtained, but much more remains to be done, and when

success finally crowns the efforts of some student it will be found that his discoveries have been accomplished through the study of electro-chemistry.

The attention of the student of electrical engineering is earnestly called to this field of electro-chemistry. Much has been done, but the possibilities for original and profitable investigation are scarcely equaled in any branch of applied science.

Did time and space permit, examples illustrating the value of chemistry to the engineer could be continued indefinitely.

Before making his selection of electives the student should consult some of those numerous works dealing with engineering chemistry alone, in order that he may know what valuable assistance is to be derived from a study of this science.

The writer does not wish to be misunderstood, he does not suggest that all electives of the engineers should be given to chemical subjects; but he does wish to impress upon the engineering student the great importance of chemistry in the daily practice of his profession. He would suggest the selection of those courses that give the broadest and most general knowledge, a knowledge showing the usefulness of the science, a knowledge that will inform him of the possibility of solving many problems through the assistance of the chemist, and, though lacking in skill of chemical manipulation himself, his mind may ever be in a state of chemical activity and prepared to take advantage of every assistance that the science may offer.

A NOVEL THREE-PHASE ALTERNATOR.

GEO. D. SHEPARDSON, M. E.

The peculiar construction of the Thomson-Houston arc light dynamo makes its transformation into a three-phase alternator an easy matter. The armature has three coils which are equally spaced and whose inside terminals are connected at a common point. The electromotive forces in the three coils may be represented approximately by sine curves whose corresponding values follow one another by a constant lag of one hundred and twenty degrees. If therefore the outside terminals of the three coils are connected to suitable collecting rings, three-phase alternating currents may be obtained when the field is separately excited.

A Novel Three-Phase Alternator.

A three-ring collecting device was designed for the T-H arc machine in the electrical engineering laboratory, but it was decided preferable to modify the regular commutator so that the machine might be changed more readily from one form of generator to the other.

The regular commutator has three copper segments screwed to brass bridges supported by brass rods passing through insulating hardwood bushings in two end flanges which are fastened to the armature shaft by set screws. Each end flange consists of a central brass disc nine thirty-seconds inch thick and three and three-fourths inches in diameter, on each side of which is a hard rubber disc four inches in diameter and one-eighth inch thick. Shellacked paper is wound over the edge of the central brass disc for insulation. Copper wire was wound in the grooves thus formed between the rubber discs of each flange, making two collecting rings which were connected to two special binding posts set in rubber bushings through the flange at the outer end of the commutator. The terminal wires of two of the armature coils were removed from the regular binding screws connecting with the commutator segments and were fastened into the special binding posts connected with the rings. The connection between the third armature terminal and its commutator segment was not disturbed. The three commutator segments were then coupled by a wire passed under the heads of the segment screws. In this way each armature terminal was connected with a continuous ring.

In order to make contact with the rings, the brushes were easily modified. One pair of the regular brushes was left undisturbed and served to make continuous contact with the commutator. The other two brushes and the cable connecting the two brush holders were removed. In their stead were placed two special brushes made of spring copper one thirty-second inch thick and three sixteenths inch wide, each one being bent so as to make contact with either of the new collecting rings on the flanges.

When thus arranged, the fields are separately excited and three-phase alternating currents may be obtained through the cross-connected commutator and the two special rings. It is a matter of only a few minutes to replace the regular brushes, remove the jumper from the commutator, replace the two armature leads in the regular cups, and change the field connections, when the machine is again ready for operation as a direct current arc light dynamo.

The machine modified as above described is style "E 12," rated as a nine light 1200 c. p. machine, but found capable of

delivering 6.8 amperes at 650 volts at normal speed of 1,000 revolutions. Arranged as a three-phase alternator, the machine gives 800 volts between any two brushes when delivering 0.5 ampere and when excited by a field current of 6.8 amperes, the armature reaction being negligible with so small current.

This machine is useful for operating induction or synchronous motors and will itself operate as a synchronous motor when suitably excited and brought up to speed. The low frequency makes it unsatisfactory for operating incandescent lamps, as the pulsations of current candle power are apparent. A third collecting ring at the pulley end of the armature and connected with the common junction of the inside terminals of the three armature coils, allows experimental study of unbalanced circuits. Also graphical and analytical determinations of the resultant of alternating electromotive forces in series may be checked by the aid of this contact with the common center.

A few details of construction may be of interest. The brass disc inside the commutator end flanges was found to be slightly out of true and a light cut was taken off in the lathe. The original paper insulation covering this brass disc was found to be too thin to stand the strain and the rings first made became grounded on the frame when the external armature circuits were suddenly opened. Increasing this insulation by the superposition of five layers of dry paper seems to have made this point safe.

In making the new collecting rings it was desirable to avoid the use of acid soldering flux and also to solder the ring quickly so as not to heat the rubber discs unduly. The ring was therefore made of No. 16 B. & S. copper wire which had been previously tinned. A small hole was drilled through the two hard rubber discs just outside of the paper insulation above the brass central disc. One end of the wire was threaded through the hole in the outer disc and was temporarily anchored to one of the binding posts. The wire was then held taut while the commutator was turned slowly winding a layer of the tinned wire across the groove. After fastening the band by a drop of solder, the last end of the wire was pulled through the hole in the inner flange and lightly hammered into place. After soldering the wire together into a solid band, the outside end of the wire was cut off close to the flange, and the inside end was brought down and soldered to the inner end of one of the new binding posts. When both bands

were built up in this way while still in the lathe, a light cut was taken off each band so as to give smooth surfaces for the brushes. The half tone engraving shows the general appearance of the modified commutator as arranged for a three-ring collector.

INSPECTION—ITS PLACE IN MODERN ENGINEERING PRACTICE.

A. C. BEYER, '96.

It is now only about fifteen years since the first inspection bureau was established in this country, which advertised itself prepared to assume the responsibility of seeing that the ideas and wishes of engineers, and purchasers of engineering materials, were carried out by the contractors who had undertaken the work. This bureau has been followed by many others, as the field, at first profitable, has opened up and developed.

Inspection was not, however, a new line of engineering work, for the advisability, economy and ofttimes necessity for it had long been recognized by many prominent engineers who were desirous of feeling assured that no defects in materials, or careless or dishonest workmanship should vitiate the results of their designs, or endanger the stability and safety of their structures. This work had usually been performed by some member of the engineer's force who was sent out for the purpose, and almost anyone was considered qualified to do it, the number of men who spent all their time at this being comparatively insignificant. But with the advent of the inspection bureau new methods were employed, more efficient and systematic service was rendered, and the inspecting engineer has now entered the field claiming recognition as another specialist in the engineering profession.

All the bureaus have a corps of men who do this work and nothing else; men who have been trained for it, who have made a special study of it, and whose judgment and ability are the results of long experience. The inspector of engineering materials has become an important and almost an essential factor in the professional practice of to-day, and his field is continually broadening. To a large extent inspection outside of government work was originally confined to materials used for structural purposes, principally to iron and steel, and at the present time its most general application is in connection with the materials for bridges, buildings and similar structures. With but few exceptions all the important structures completed during the past few years, or now being built, have been given a careful and thorough inspection in all stages of the work. And many others of less

importance are examined and passed upon by inspectors in one or more stages, usually either in the mill or shop. Many railroad companies have men stationed at the shops where their bridges are being turned out to see that both in quality and quantity the work comes up to the desired standard. New York City appoints its large force of building inspectors through the municipal civil service commission, and while they cannot detect careless or dishonest work as easily or to such an extent as it could have been done at an earlier stage, yet their reports show that they are able to correct a great deal of it, and in a city where steel-frame and cast-iron-column construction is so common, the importance of having this examination, when private inspection is often omitted, is readily seen. Other large cities have followed New York's example.

Inspection in connection with structural work naturally divides itself into three stages, technically known as mill, shop and field inspection, following each other in the order given and all considered essential in the best class of work. Inspectors have not yet specialized to any large degree as to these three classes, but do more or less of all. By this is not meant to imply that one man follows a given job through all of its stages, for this is quite unusual. He who approves the material at the rolling mill is done with it there, as is also the man at the bridge shop when the built-up work is shipped away to the site where it is to be erected under the supervision of a third party. This method is certainly as economical as it is efficient; it furnishes a means of checking the work, since what is overlooked by one is quite likely to be seen by the next, especially when, as is usually the case, the parties for whom the work is being done do their own field inspecting. Again, under this method the inspection bureaus can have men stationed continuously for considerable periods of time at the various mills and shops in a certain territory, thus enabling them to more easily secure work that comes there, and to do this at a greater profit in that one or two contracts will pay expenses while all others that may be obtained at the same time are almost clear gain. There are, of course, many men who never leave the mills, for a great deal of material, such as eye-bars, beams and rails, needs no other inspection. As a result the number of mill inspectors is larger than that of any other class.

It is easy to see that the work of an inspector at foundries and

rolling mills is of the utmost importance. The engineer who designs the structure has counted on using material of a definite strength and possessing certain specified physical and chemical qualities which he regards as more or less essential, as shown by the past experience and observation of himself and others. He knows that he can obtain such material, and, being ready to pay, has a right to expect it. The inspector, as his authorized representative, makes tests and examinations and accepts or rejects the material according as, in his opinion, it meets the requirements of the specifications or not.

Without going into detail as to the great variety of tests which are made, depending on the kind of material, the purpose for which it is intended, and the ideas of the engineer who draws up the specifications, it can be said in general that for structural work an inspection of the surface of the material when finished and the examination in a machine of test pieces of specified shape, size and number are all that are considered necessary to determine whether the metal is suitable or not. From the surface the inspector, by simply looking it over and using a file or chisel, endeavors to ascertain whether there are seams, cracks, pipes, laps or other defects resulting from the melting or rolling which tend to injure the soundness of the material in any way. And an experienced man can in this way detect faults which another would not be able to see with an ordinary magnifying glass. Hot and cold bending, nicking, drifting punched holes and other tests are often specified and used as a means of revealing any unsoundness that may exist. The testing machine gives data from which the tensile strength, ductility, elastic limit and reduction of area are obtained. Through their own laboratories, or others to which they have access, the bureaus are able to determine the chemical properties of the materials from drillings and specimens sent them by their inspectors. But this is not very often done, as all the large mills have their own chemist who makes analyses, and these are in most cases accepted as correct.

After being accepted the material is ready to be shipped to the bridge shops, where the structure is to be built in accordance with shop drawings made from general sketches furnished by the engineer. The construction work is now watched by the shop inspector, who in general is expected to see that it is made as called for on the drawings, and that the workmanship comes up to the

specifications as regards neatness and finish. His first duty is by far the easier and can be performed by almost anyone who can read a shop drawing. The second involves a great variety of details, including the matter of painting, the tightness and appearance of rivets, the accuracy of connections, the condition of surfaces in contact and the innumerable other small points which go to make up the difference between first-class and careless work. The shop inspector, if not a practical machinist, must have a large acquaintance with the methods and tools of the latter, and the kind of work he can do. To him are referred all mistakes and difficulties which so often arise during the construction of the work, and the good judgment which he must exercise on such questions can come only with experience and intimate knowledge of such matters. He needs something more than a technical education and the ability to understand a detail drawing.

Of the three classes of inspection on structural work the one which, if the others were to be omitted, would best insure good results, is undoubtedly that in the shop. As has been suggested, the inspection at the mills is, even with the best men, largely superficial, being usually but a more or less hurried surface examination with the pulling of a few tests, which must often fail to reveal all defects. That this is so is shown by the fact that at the shops during the various processes and handling to which the material is subjected, flaws are discovered whose presence was not even suspected by the man at the mill. It is claimed that iron which will stand the treatment it gets in a shop, where it is punched and sheared and drilled and pounded, and shows no flaws, is good material. And it certainly is a trying ordeal. Again, the custom of engineers of using a large factor of safety—usually four or five—makes it possible to allow for a certain amount of unsoundness not shown on the surface, even if it were not the general practice of all reputable mills, for the sake of their business character and standing, to endeavor to turn out good material. Thus by giving the shop inspector power to reject everything that shows signs of weakness, one can be reasonably certain of securing good work with shop inspection alone, if it is necessary to omit one or the other.

On the other hand, however good the material is, it may be so maltreated in the shop as to entirely undo the care taken in pro-

ducing it at the mills, and this contingency must be guarded against. Pursuing this argument further, it may be claimed that mistakes and carelessness in erecting the structure can undo all the care and good work that the shops may have contributed and therefore a man to watch against this is very essential in the field.

And so he is. But with good connections made in the shop and care taken before shipping to plainly and correctly mark all pieces, his duties become very light and consist principally in seeing that tight field rivets and good connections are made. His is, of course, a very responsible position, and wise judgment and good common sense are qualities that he can always find use for. As an example of some of the points over which he may have control, the case of a bridge in a large city may be mentioned. Here the field inspector had to pass judgment on not only the erection of the structure itself, but on the masonry substructure, the concrete foundation and asphalt surfacing of the pavement, and the laying of the rails and stringing of the wires of an electric railway which ran across the bridge.

As the inspector is expected to see that the engineer's ideas, as they are expressed in the specifications, are carried out, it needs no argument to show how important it is that these latter should be plain and explicit and as nearly as possible capable of but one interpretation, namely, that intended by the engineer. It is in this matter of indefinite specifications that inspectors often find their duties made hard and unpleasant. It does not suffice to say in a general way that all workmanship shall be first-class, but definite clauses should exist stating in what particulars the work should be first-class. The specifications of the New York Central & Hudson River Railroad can be named as good examples of explicit statements on many points, enabling the inspector to secure a very high grade of work which cannot but prove satisfactory to the company.

The relations existing between the inspectors and contractors are as a rule, and indeed should be, characterized by a spirit of courtesy and mutual helpfulness, with a desire to work together for the best results., The inspector is not usually of the opinion that he is the only honest man in the transaction, and his unceasing watchfulness is not because he thinks someone is trying to hoodwink him, but because he understands that human nature is

not infallible and the common laborer in a bridge shop or mill is no better than other men.

Having now considered at such length the inspection of structural materials, a brief reference, at least, should be made to that given to others. Its application to these has not, however, become as general as to the former. Building stones, paving materials, limes and cement, wood and other materials may be mentioned. The Pennsylvania Railroad is an example of railway companies which have an organized corps of inspectors as one branch of the engineering department and their duties are performed in connection with ties, rails, splices, bolts, spikes and all manner of railway supplies.

While preparing this paper letters were sent out to a half-dozen or so of the prominent inspection bureaus in the country asking them for information regarding the preliminary training or experience that their inspectors had before entering upon the work. From the replies received the following figures have been compiled:

Number of inspectors reported	80
Number of these who were technical graduates or college men	49, or 61 per cent.
Number of these who were skilled mechanics, but not college men	21, or 27 per cent.
Number of these who were experienced shop men, but not skilled mechanics	10, or 12 per cent.

From these figures it would seem that a very large proportion of the men engaged in inspection have had a college training. They are not all civil engineers, electrical and mechanical engineers being found among the number. As has been stated before, an inspector must know a great deal that is familiar to a skilled machinist, and if as a college man he does not have this knowledge he has to pick it up as best he can, for it is absolutely essential.

May we, in closing, be pardoned for letting the imagination carry our thoughts forward into the future when the time will come in which, with all the other varied specializations of the engineering profession, the inspecting engineer shall be recognized as such by the engineering fraternity; when technical schools shall have chairs of inspecting as they now have of hydraulic or sanitary engineering; when after the preparatory years, with their curriculum of general studies, special attention will be paid in the

upper classes to such work in practical botany and geology, the chemistry and testing of engineering materials, the study of processes of manufacture, and shop, foundry and machine practice as will give the inspector some of the many things he has to become acquainted with when he engages in his work. Nothing can, of course, take the place of actual experience, but special training can prepare a man so that he will receive the maximum benefit from this experience. Does this seem to be a fanciful picture? Time will show.

NOTES ON THE HEAT TREATMENT OF IRON AND STEEL.

HARRY E. SMITH, M. E.

To the engineer who is brought into intimate contact with the uses of iron and steel, the processes of their manufacture are of interest. Their varying characteristics during and after casting, rolling, forging, annealing or tempering, form a fruitful source of study and investigation, while some knowledge of the changes that these materials undergo in chemical and physical qualities, during these operations, is essential to their successful use. Enormous advantages may be anticipated from the systematic study of "heat treatment" when applied to iron and steel, of which we now know but little.

Let us consider some of the characteristics which a piece of tool or cast steel can be made to assume by the application of heat. If a bar of tool steel be nicked at intervals, then heated from the temperature of the air at one end, to that temperature at which the corners just begin to melt, at the other end, then quenched and the bar broken at the successive nicks, the structure of the bar will be found to have undergone varying changes.

Beginning at the end which was not heated above the temperature of the air, and passing to each successive piece we will find the grain or structure of the steel to be the same as that of the original bar until we reach the portion which was heated to a full red. Here the grain suddenly changes to an extremely fine and nearly amorphous form, and beyond this point the crystalline structure becomes more and more coarse.

There appears to be a maximum degree of coarseness, or size of grain, for each temperature, varying with the composition of the metal and rising with the sectional area and with the temperature and time of exposure.

The rate of cooling also appears to have some influence on the size of the crystals, especially in large forgings.

A bar of steel 1.5 inches square, when quenched from a very high temperature shows on the outside coarse crystals. They become rigid so quickly that they preserve the form acquired at the high temperature. The interior of the bar is flaky and might even be called fine grained, much finer, indeed, than if the bar

had been cooled slowly. This is probably due to the internal stresses, which tend to break up the crystalline structure of the center of the bar. It appears to be a general rule that the finer the grain, other things being equal, the better the condition of the steel to resist shock. Thus the means of acquiring and preserving this grain are of great importance, and not less important are those of avoiding the coarse grain. This fine grain may be obtained in two ways, or under two sets of conditions, one, by suddenly cooling the steel from the molten state, and the other, by producing a change in the carbon from the nonhardening to the hardening form at the full red heat. The first method probably breaks up the coarse structure due to the high temperature by the intense internal strains induced, while the second is due to the sudden rearrangment of the crystals, which seems to be so violent as to efface all previous crystallization.

Forging and rolling iron or steel oppose and break up crystallization, if they are performed while the iron is at or above the red heat.*

But if forging or rolling be completed at a high temperature and the piece be then slowly cooled, the higher the temperature at which the forging ceases, the coarser the grain and the worse the steel, hence the importance of a low finishing temperature in this work.

The superiority of thin over thick forgings, which is usually attributed to the extra work performed on them, is probably due in large part to the usual low finishing temperature of thin or small pieces.

An experiment performed by a competent metallurgist serves to illustrate this fact. Three uniformly heated test bars, cut from a single ingot, were carefully rolled, one very fast, one normally, one very slowly. Their merit was found to be inversely as their finishing temperature.

As power, hence cost, is saved by rolling or forging at high temperatures, means have been proposed of accelerating cooling after forging has ceased. Such a method is used in the Coffin Rail Process, where the rails are immersed in water or have streams of water play on them immediately after coming from the rolls, until their temperature falls to the dark red, from which

* Rivets are said to fail at the head which is not struck, rather than at the struck head. The blows of the riveter prevent and overcome crystallization and consequent brittleness.

point the rails are cooled slowly to the temperature of the air.

It will be found that the pieces of our experimental bar, having the finest crystalline structure, exhibit the greatest ductility, toughness and shock resisting power.

This fine grain is then very desirable in the finished product, whether it be rolled or forged iron or steel, or steel castings.

This structure cannot be obtained by any system of cooling the pieces but can be produced by reheating after cooling, to the full red, and then cooling quickly. The more or less complete restoration of overheated and even burned steel may be accomplished by reheating to the red heat, followed by forging and then quickly "quenching" or slowly cooling.

The proper annealing of steel castings or forgings relieves internal stress, effaces columnar structure, gives fine grain, increases strength and ductility and raises the elastic limit.

On account of the tendency of steel to crystallize above the full red heat and also while the temperature is falling to the dark red, the proper heat for annealing is the full red, followed by quickly cooling to the dark red and then slowly cooling through the remaining range of temperature.

The above treatment is applied to car axles and other steel forgings, by the Cambria Steel Co., of Johnstown, Pa.

Cherrioff gives the following as the results from three samples cut from the same bar of steel. After forging the samples were treated as follows:

A was slowly cooled.

B was reheated to a full red and then slowly cooled.

C was reheated to a full red, quenched to a dark red and then slowly cooled.

A broke under a single hammer blow.

B required five such blows.

C could be broken only by a blow of a five-ton steam hammer.

It will also be found, on applying tests for hardness to the pieces of our experimental bar, that beyond the point where the crystalline structure changes suddenly, the steel has become extremely hard and especially very brittle toward the end that was exposed to the highest heat.

Chemical as well as physical change has also taken place in the steel. The carbon it contained exists, in combination, in at

least two perfectly distinct modifications called cement and hardening carbon.

The chemical evidence of these two forms was first demonstrated by Faraday in 1822, when he found that steel, when suddenly cooled, dissolved completely in dilute, cool, hydrochloric acid, and when the steel was annealed it left a carboniferous residue. In the first case, the carbon is said to be in the hardening form, in the latter, in the non hardening or "cement" form.

The exact difference between the two forms of carbon is not definitely known, but their effects upon the qualities of the steel are quite evident.

The carbon in our samples will be found in the cement form in all the pieces that were not heated above the full red heat, and in the hardening form in all pieces heated above this temperature.

In annealed steel practically all the carbon is in the cement form, while in hardened steel scarcely any of it is, from which we infer that it is in the hardening state.

In tempered steel an intermediate proportion is in the cement state.

In molten iron and steel the carbon is probably in a condition closely related to the hardening carbon, since on suddenly cooling from fusion we find it chiefly in this form.

According to Brinnell's experiments the change from cement to hardening carbon does not take place below the red heat but occurs suddenly and completely at the red heat. This can be proven by heating a piece of steel, in which the carbon is initially in the cement state, up to nearly the red heat, and then quenching, when the carbon will be found still in the cement state, while if quenched from the red heat or above, the carbon is found wholly hardening. On the other hand, if we heat a bar above the red heat and slowly cool it, the carbon remains in the hardening form until the temperature at which red just shows in the dark, when the carbon begins to change slowly to the cement form, and so continues until about the temperature of the air is reached.

That the transfer of carbon from the hardening to the cement form may occur at very low temperatures is suggested by the reported fact that table knives gradually lose their hardness if habitually washed in hot water, or that razors if used cold retain their temper longer than those that are warmed before using, though for other reasons the razor may cut better while hot than

while cold.

Other phenomena indicate an important chemical change at a temperature somewhere between the full red and the dark red heats.

The temporary magnetism, whether induced by an electric current or by another magnet, suddenly vanishes at this temperature, and its thermo-electric behavior is abnormal.

Here a remarkable evolution of heat takes place, known as the "after glow." This is accompanied by a marked rise in temperature, a sudden expansion, and a great temporary increase of flexibility.

The late John Coffin, of the Cambria Steel Co., found that the expansion of a bar of iron when cooling through this range increased greatly with the proportion of carbon. A four-foot bar with 0.90 per cent of carbon, in cooling from an orange heat, contracted 1-8 in., re-expanded 1-32 in., then again contracted 9-16 in. A similar bar with 0.17 per cent of carbon contracted regularly during 45 seconds, then ceased to contract for 20 seconds, then again contracted. In iron containing a very small per cent of carbon, no perceptible decrease in the regular contraction was noted.

An experiment which gives striking illustration of the violent rearrangement of the molecules of steel when heated to the full red heat was performed before the Philadelphia meeting of the American Society of Mechanical Engineers, November, 1887, by Mr. Coffin.

A piece of one-fourth inch square tool steel was broken, the fresh fractures placed in close contact, the pieces inclosed in platinum foil to exclude the air and heated to the full red in the flame of a Bunsen burner. After cooling it was found that the pieces were very perfectly joined. A number of larger pieces, both soft steel and tool steel, were shown at the same meeting, that had been united in a similar manner, which, by their color, sharpness and freedom from scale indicated that they were united either much below the ordinary welding temperature or with the nearly perfect exclusion of oxygen.

Another critical temperature for both iron and steel is at the so-called "blue heat," which is from 450° to 600° F. Here iron and steel are much more brittle than when cold or at redness. This heat, however, does not seem to leave any bad effect on the

iron so heated. But if the piece be worked in this range of temperature, it will retain the brittleness after cooling and show a great loss of ductility as measured by the bending test, although it has not been conclusively proven that there is a loss of ductility when the piece is pulled apart by static tensile stress.

The loss of ductility and shock resisting power is not due to any incipient cracks, as can be proven by the restoration of the former qualities of the metal by reheating to redness or by annealing. Several experimenters have called attention to the increase of "blue shortness," or the effects of "blue heat," with the increase in percentage of non ferrous elements present in the iron, but these reported facts have failed to be fully sustained by recent experiments. There seems to be some close relation between the effects of "blue shortness" and "coldworking," but the injurious effects of the former are more intense than those of the latter.

Soft steel plates which have cooled to the blue heat, while in the process of rolling have been reported by Bessemer and others to have been shattered in the last passage through the rolls.

While blue-working lessens ductility, it is not always fatal to the metal. Examples may be cited in proof of this. In hand riveting the operator usually continues hammering while the rivet cools past this critical temperature, and yet few rivets have been known to fail from this cause alone. Shafting is often heated to blueness by a dry bearing while under stress and shock, but is apparently uninjured.

Blue-working without subsequent annealing is prohibited in boiler work for the United States navy, but not for hull work. Many good American and British engineers do not forbid blue working in their practice.

There is another phenomenon exhibited by iron and steel when cooling from the molten state, that is, the evolution of large volumes of gas, which assist in the formation of blowholes and other imperfections against which the designing engineer has to contend. These gases have been found to consist principally of nitrogen, hydrogen and carbon oxide gases, and may be held in the iron in several conditions:

1. In chemical combinations. 2. In solution. 3. In adhesion. 4. Mechanically retained.

In the first three conditions the gases are no longer gaseous but rather in a condensed form. This condition of the gas can

be illustrated by some examples. A piece of charcoal will, at atmospheric pressure, absorb ninety times its own volume of ammonia gas. The ammonia could not possibly be still in the state of a gas, for if it were, its pressure would burst the charcoal. Similarly, electro-deposited iron may hold 248 times its own volume of hydrogen. These gases are evidently in a liquid or solid form.

It appears that iron, when molten, absorbs nitrogen, hydrogen and carbonic oxide gases freely, and in solidifying evolves them, since it is no longer able to retain them. The escape of these gases is what gives the steel maker and foundry man their trouble, as gas which is caught in the pasty mass of iron forms minute bubbles which enlarge, by accretions from the adjacent metal, into openings called blowholes. The gases in these openings, if unable to swim to the top of the casting, cause the metal to swell or rise, or, if they escape, cause boiling and scattering, which produces unsound pieces.

A grey cast iron which passes quickly from the liquid to the solid state is less likely to form blowholes than white cast iron, which passes through a pasty condition, unfavorable to the escape of gases.

The more free iron is from carbon, silicon and manganese, the more does it tend to form blowholes. High carbon steel is usually comparatively free from blowholes, but is more liable to form openings at the center of the ingot, called "piping," due to its greater contraction in cooling.

Irons containing a large percentage of phosphorus, however, disengage gas much more violently and tend to produce unsound castings. The escape of gas continues for some time after the iron has solidified, and can be obtained from the minute cavities of all irons by subsequent borings which penetrate these openings.

Sir William Bessemer proved that the escape of gas from molten steel was largely governed by the existing pressure. When a partial vacuum was formed over the solidifying ingot the evolution of gas was much more violent. If a pressure were produced, the solubility of the gases in the iron was increased, and any gas which was evolved during solidification would be more promptly expelled. This process, which he called "liquid compression," was described by him in 1856. It remained, however, for Sir Joseph Whitworth to put this knowledge into practical use.

In his process the steel is cast in a special mold or flask of great strength and so arranged that the gases can escape. The metal while solidifying is subjected to a pressure, occasionally reaching 20 tons per square inch of horizontal cross section. This pressure hastens the discharge of the evolved gases and prevents to a considerable extent the formation of blowholes, and by producing a flow of metal to the contracting center of the ingot, partially overcomes piping, the ingot being actually compressed about one-eighth of its longitudinal dimensions. The Bethlehem Iron Co. uses this process in the steel castings from which large shafts and other structures are forged.

It is not the intention of the writer to do more, in this brief article, than to outline some of the physical and chemical changes which may take place in iron and steel while being formed for the many purposes of the engineer.

There are many phenomena in this field, which should be investigated and the possibilities which may be derived from a more complete knowledge of this most valuable metal, iron, are far reaching.

IMPROVEMENTS IN THE THREE-WIRE SYSTEM.

TRUMAN HIBBARD, '97.

In the year 1880, after costly and tedious experimenting, Edison introduced his incandescent electric light on his low pressure constant potential system of distribution, as a competitor for commercial lighting. The difficulty of making a high voltage lamp required the use of low voltage lamps, 50 to 125 volts, and therefore low voltage and heavy currents on the distributing lines, causing a heavy loss therein.

In order to diminish this loss, Edison devised his three-wire system for which the United States patent No. 274,290 was granted to him March 20, 1883. A similar patent was granted to Dr. John Hopkinson in England July 27, 1882. By this system the pressure on the mains is doubled while the same low voltage lamp is used, allowing the carrying capacity of the line to be decreased to less than 40 per cent of its original capacity and still have the same per cent lost on the line.

Where a single generator is used it must generate the whole pressure. Fig. 1 shows the original method proposed and employed by Edison for two machines operating on the three-wire system. When more than two machines are desired they are connected two in series, and as many pairs of these series as desired are operated in parallel, as shown in Fig. 2.

It will be readily seen that when the current consumed on each side of the middle wire is the same, the fall of potential between it and either main will be the same, and it will have a potential midway between the two, as it also has at the generators. Therefore the potential is the same at both ends of the middle wire and there is no tendency for current to flow. It is therefore called the "neutral wire."

The increase of pressure to twice its former value allows a decrease of current to one-half its former value, and as the line loss is proportional to the square of the current, this decreases the line loss to one-fourth its former value, or allows a conductor of one-fourth the carrying capacity. The neutral wire is usually one-half the size of the outside mains and this makes the total weight of the conductors of a three-wire system five-sixteenths of that for a two-wire system furnishing the same number of lamps with

current. This enormous saving in one of the largest items of expense has led to an almost universal use of the three-wire system for low pressure distribution to distances over a few hundred feet and under a mile. Of the 207 miles of underground mains of the Edison stations in New York City in 1896, all but seventeen one hundreths of one mile are of the three-wire system.

This economy of line copper is the sole advantage of this system. Opposed to this are the following disadvantages:

1. The necessity for two dynamos or a complicated compensating apparatus.

2. The wiring is slightly more complicated involving the installation and maintenance of three instead of two conductors, and more complicated switchboard apparatus.

3. Sometimes the system may become badly unbalanced and cause some of the lamps to have a higher pressure than either of the generators (1). When the system is badly unbalanced, if by any means the neutral conductor should be broken it would mean sure death to the lamps burning on the light side. But destructive unbalancing can usually be guarded against by judicious planning at the beginning and care in later extensions.

The one advantage remains so much greater than all the disadvantages, that as stated it is almost universally used for low potential distribution, where the plant is of sufficient size to warrant the use of two machines.

From the three-wire system five-wire systems using four machines and even seven-wire systems using six machines were easily developed (2). But the greatly increased complication of these systems prevents their use only for very dense supply. Edison also proposed four- and six-wire systems using three and five machines, but neither of these systems can be divided into other systems with a smaller number of wires, and still properly maintain the balance, hence they are rarely used. A great deal of effort has been directed toward improvements and simplifications of the system. Edison suggested using a third brush for the neutral wire, on a single bipolar dynamo, but the brush caused vicious sparking on account of the conductors being in a strong field when passing under the brush, and we find no accounts of its successful use.

Edison also proposed the use of a storage battery, with the

neutral wire connected at the middle and one main at each end, the batteries being in series, and an adjustible resistance being put in series with each main for regulating the pressure of each side, which is manifestly a wasteful method.

Rankine Kennedy in England patented a new machine in 1882 which he called a "multiple current dynamo"(3). His scheme was to use a two-pole armature in a four-pole field (Fig. 3). The

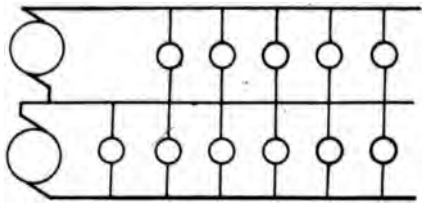


FIG. 1

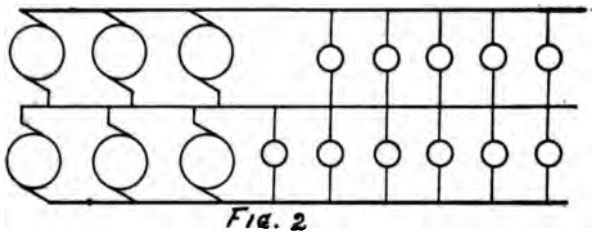


FIG. 2

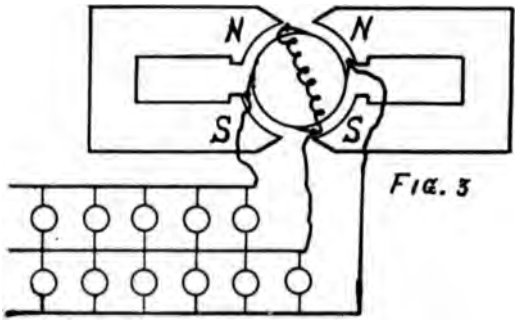


FIG. 3

windings of the fields were so arranged as to bring two north poles together and two south poles together. The main brushes collected current from the usual neutral points between north and south poles. Two other brushes were placed on the commutator in the gap between the two parts of each north and south pole, and connected together, and to the neutral wire of a three-wire system. These auxiliary brushes being at a point where the

armature conductors were generating no pressure, on account of the gap in the field, gave very little trouble from sparking when the load was fairly well balanced between the two sides.

It is interesting to note that this machine was patented before Edison's three-wire system was brought out, and originally built for another purpose. In 1895 Kennedy proposed using the machine at 460 volts on the outside mains and 230 volt lamps on each side. Motors at 460 volts could be used directly from the two outside mains as also arc circuits at constant potential. He also suggested using a six-pole machine of similar design on a five-wire system.

In 1880 Herr Hermann Muller(4), of Germany, proposed to use only a single generator with two brushes, generating the pressure on the outside lines, transmitting the current on two wires to the point of distribution and there using an auxiliary small machine of special design to convert it into a three-wire system and effect a balance, distributing thence, on the three-wire system. Fig. 4 shows the arrangement. The balancing machine had one pole split and the other solid, and the two main brushes, 1 and 2, bear on the commutator on the usual neutral points between north and south poles. These brushes are connected directly to the mains from the generator. A third brush, 3, connected with the neutral wire bears on the commutator in the neutral point formed by the gap in the north pole, and is half way between the main brushes. When the load is unbalanced as in Fig. 4, the difference of the two currents flows from brush 3 to brush 1 through the armature conductors, acting as a motor to drive the armature. This motor action develops a pressure in 3 2, of the armature which is added to the pressure already existing there, thus raising the pressure on the heavily loaded side of the system. One-half of the armature always acts as a motor; one remaining quarter acts as a dynamo, and the other quarter as a motor, these quarters changing functions as the overload varies from one side to the other. When the system is balanced the machine runs as a motor without load. This particular method does not seem to be much used, though methods quite similar are often used.

A set of storage cells(5) has been used in place of the equalizing machine of Muller's scheme, by connecting the ends of the set of cells to the mains and the neutral wire to the center of the

battery as in Fig. 5. When the system is unbalanced, the heavily loaded side of the circuit receives current from that half of the battery while the other half of the battery is charged.

This method affords no economy in first cost but at times of light load the batteries may furnish all the current that is required and allow the machinery to be shut down.

Mr. R. E. Crompton([6]) was the first to use storage batteries in connection with the three-wire system in Europe. He employed them in a plant at Vienna in 1886 and the system was still in successful operation in 1895. He used them in many subsequent installations in Great Britain with good success. The use of accumulators also gives a more uniform load for the generating machinery, being charged by the lines at times of light load and discharging to the lines in times of heavy load, thus allowing the machinery to be operated at a higher efficiency. By slightly shifting the point of connection of the neutral wire, the pressure for the two sides may be very closely regulated for almost any degree of unbalance. Storage batteries may also be used in connection with one generator and a five-wire system. A large plant using accumulators on a three-wire system was installed in Mulhausen, Germany, in 1888 and is giving excellent economy and regulation([7]).

In 1887 Elihu Thomson patented a method of using storage batteries([8]) in connection with a three-wire system, in which he used a battery giving only one-half the pressure of the outside mains. By means of a revolving commutator he rapidly connected the battery first to one side and then to the other so that it would receive a charge from the side of light load and instantly be switched over and deliver it to the heavily loaded side. This does not seem to be of any commercial value.

Thomson also proposed several other methods. One was to use a small motor([9]) mechanically connected to the single generator, and an automatic switch to keep the motor always connected into the light side of the system and always running as a motor, using the surplus current and converting it into mechanical work to assist the engine to drive the generator. The field of the motor had a shunt winding across the outside mains and was differentially compounded by a series winding of the neutral wire, so that as the load became more unbalanced the motor tended to speed up. The connections are shown in Fig. 6. The

automatic switching arrangement for throwing the motor connections from one side to the other depended on the differential action of two sets of coils on an iron core. Fig. 7 shows the arrangement of the switch in which coils N N′ carry the current in the neutral wire, coil A the current in main A and coil B the current in main B. When any current flows in the neutral wire one of the sets of coils will act together and the other set act in op-

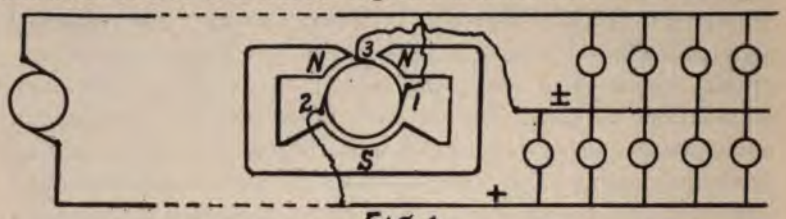


FIG. 4

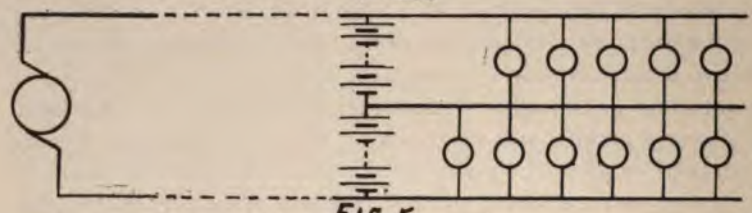


FIG. 5

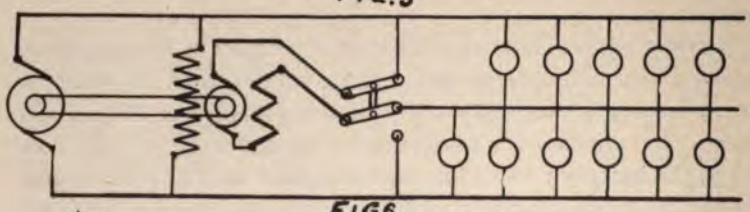
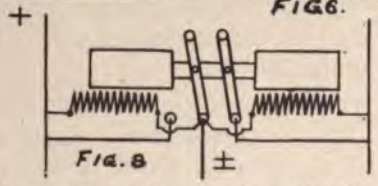


FIG. 6.



position, so that the core is pulled in the direction of the two coils acting together, in the figure, N′ and B. When the current in the neutral changes direction, due to a change of balance, the other two coils act together and draw the core in their direction throwing the switch and changing the connections of the motor to the lightly loaded side.

Another switch actuator for controlling the same switch, for

the same purpose was proposed, and is shown in Fig. 8. It depended upon the difference of potential of the two sides of the system but was found not to be sensitive to less than about four volts difference between the two sides, and thus caused a bad flicker when it did throw, and it was abandoned.

Mr. E. W. Rice, Jr., patented in 1891 a method([10]) of using a single auxiliary machine permanently connected to one side of the circuit, and mechanically connected to the generator as in Thomson's scheme. The electrical connections were never broken, but on the other hand it changed its function as the balance changed, running as a motor assisting the engine when the load was light on its side, and as a dynamo helping to supply the current when its side was heavily loaded. To cause it to change its functions automatically the field was wound with a shunt across the outside lines and a series winding of the neutral wire. Then as the neutral carried current one way the series winding assisted the shunt, making a strong field and causing the machine to generate current. When the neutral current reversed the series opposed the shunt and the machine tended to speed up in the weak field and run as motor.

Mr. H. Ward Leonard modified this system by using a small generator and motor connected together near the center of distribution([11]). (Fig. 9.) One machine was connected to the outside mains and the other to the neutral and one of the mains permanently. When that side was lightly loaded machine A ran as a motor driving B as a dynamo, and in parallel with the main generator, supplying current to the mains. When the balance changed A would become a dynamo driven by B, supplying current to its own side. The two small machines could be placed some distance from the central station and required little care, and gave quite satisfactory results.

Another method proposed by Thomson([12]) was to use a motor generator, in which two armatures were connected rigidly together. They were connected in series across the outside mains and the neutral connected in between them (Fig. 10). Then the armature on the light side drives the other as a dynamo at a slightly increased speed, thus developing a slightly higher pressure on the heavily loaded side, and thus maintaining the lamp pressure. As the balance changes from one side to the other, the armatures exchange functions automatically. By

means of a rheostat in the field circuit of one of these small machines, the regulation may be made quite close by constant attention.

In this method of regulation the C R drop and the C^2 R losses in the armatures are detrimental to close regulation and should be reduced to a minimum in the design.

Under balanced load both armatures run as motors, if the fields are of the same strength, dividing the friction load between them. This method of compensation is perhaps the one most commonly used, aside from the original two dynamo system. The windings of both armatures may be on a common iron core, placed in a single field, and provided with two commutators. By this method armature reactions are neutralized and the commutation is sparkless at all loads, and the friction loss is reduced, but the advantage of independent field regulation is lost.

A combination of the motor-generator and accumulators for compensating is used with good success by the Burnley station, at Burnley, England([13]). (Fig. 11.) The motor generator is built in one machine and connected between the two armature windings to the neutral wire. The neutral is also connected into the middle of a large storage battery giving something more than the generator pressure. The end of one armature winding is then connected to a battery regulating switch B, and the end of the other armature to another similar switch, D, at the other end of the battery. Two similar switches on the other side of the batteries as shown, A and C, connect to the outside mains. These switches are so arranged that a few more or a few less cells may be put in circuit at will, and by this means the bad effect of armature losses are overcome. For instance, if the plus side were loaded heaviest and the pressure low, moving the switches A, and C, to the left, raises the pressure between plus or minus by putting more cells in circuit, and at the same time lowers the pressure between plus or minus by cutting out some cells, thus maintaining the pressure at the lamps the same in each. By moving B and D to the right the armature on the light side speeds up as a motor, and drives the other armature as a dynamo, delivering current to the heavily loaded side. When the overload changes to the other side, the switches must all be moved in the opposite direction, though not necessarily the same amount for each, and the armatures exchange functions. The motor generator tends to

keep the state of charge the same in both sides of the battery, which is quite desirable. The accumulators furnish all the required current for hours of light load, so that the engine need only be run during hours of heavy load. This method is somewhat complicated and perhaps expensive to install, but it is claimed that the operating force is largely reduced and the economy of operation increased.

Mr. A. Churchward has perfected a motor generator([14]) of the single machine type, to be used as an equalizer on three-wire systems, which has met with good success in New York during the last three years. Experience has shown that the capacity of the equalizer need be only ten per cent of the load it is to equalize.

A "double voltage" dynamo([15]) for operating the three-wire system was brought out in 1894 by Mr. Fuller of Detroit. It was simply two generators built in one having two commutators and operated very much as two dynamos, except that independent field regulation was lost. It has not come into general use.

In 1893 Dobrowolsky ([16]) devised an ingenious compensating device to be used with a single generator, which was exhibited at the Lyons Exhibition in 1894 by the Five-Lilles Co. (Fig. 12.) The method was to connect the two ends of a choking coil to diametrically opposite points of an ordinary Gramme armature, used as the generator armature. Then the neutral wire was connected in to the middle point of the choke coil. When the machine is running there is an alternating pressure set up between the points where the choke coil is connected to the armature, which would send a large current through the coil were it not for the choking action due to the high selfinduction of the choke coil. By making the selfinduction quite large, the ohmic resistance of the wire coil may be made quite small and still only a very small current will get through, due to the alternating pressure. The middle point O, of the choke coil winding is always at a potential midway between that of the ends A, B, and at the same time the difference of pressure between O and brush N is equal to that between O and brush P. Now by connecting the neutral wire to the point O and the brushes P, N, to the outside mains, if the load is unbalanced as shown, the neutral current will come back to O and there divide and pass through the windings of the choke coil, to the armature since it is continuous and causes no selfinduction. Since the difference of pressure between O and A, and O and B, is always maintained the same

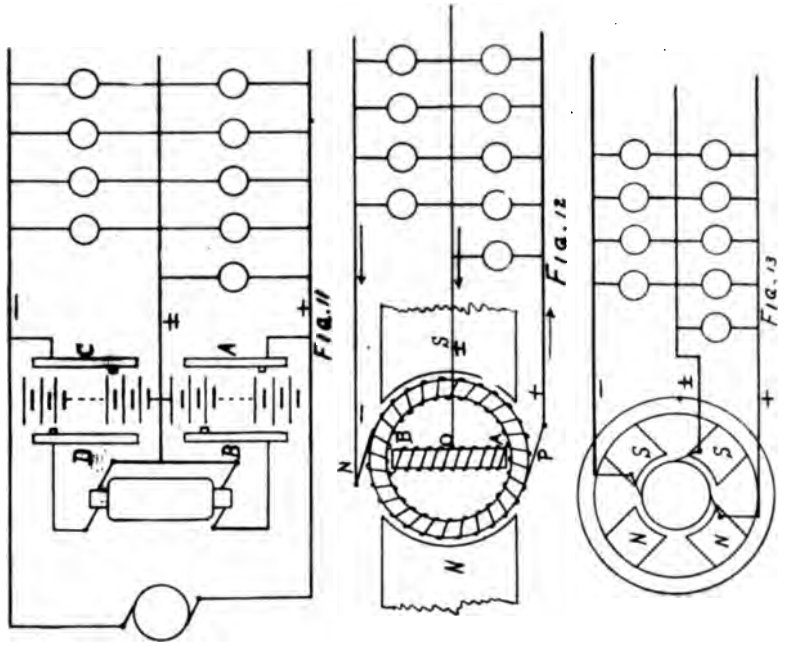


Fig. 11

Fig. 12

Fig. 13

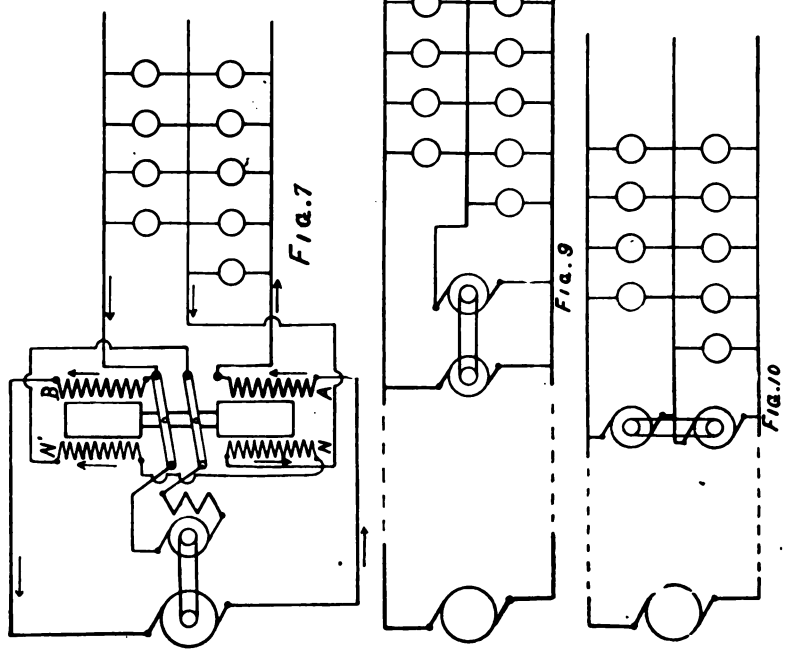


Fig. 7

Fig. 9

Fig. 10

by this choke coil, for all conditions of balance we will have practically the same pressure between the neutral and each outside main, at the station. As the load on one side may quite largely exceed that on the other it may be desirable to raise the pressure on the heavily loaded side above that of the other to take care of the drop on the neutral line, which is manifestly impossible with this arrangement. It was found to work well only on pretty evenly balanced systems.

A small machine of this type may be used as a tension regulator at any distance from the generator, just as a motor generator would be used. Usually the choke coil is placed outside the armature and the connections made through collector rings.

Pilcher suggested a modification([17]) of this machine in which a Gramme armature is wound in the usual manner, and in addition, an auxiliary winding of smaller wire, of sufficient size to carry the neutral current, and of exactly one-half the number of active turns of the regular winding, is evenly distributed over the core. The two ends of this auxiliary winding are connected to two points of the main winding diametrically opposite, in a two-pole machine, and the middle point of the auxiliary winding is connected to the neutral wire through a contact ring and brush. Thus the two halves of the auxiliary winding are connected in series, and the pressures generated in each half added together. This pressure is alternating and its maximum value is equal to that of the main winding. By this arrangement the pressure generated in the auxiliary is at all times equal and opposed to that impressed at the two points of the main winding, to which it is connected. Thus a counter E. M. F. generated by the fields and auxiliary winding checks the flow of alternating current, instead of the selfinduction as in Dobrowolsky's machine. However, this method does not afford any means of independently regulating the pressure in each branch of the system.

Apparently the most satisfactory method proposed, up to this time, is that used by the A. E. G. Co., formerly Lahmeyer & Co., of Frankfurt on the main([18]). The machine was invented in 1894 but did not reach the market until late in 1895. Several of the machines are now running successfully.

To divide the total pressure in halves they use a third brush between the positive and negative brushes, and suppress sparking by the use of a four-pole field in which two adjacent poles are

north and two are south, as shown in Fig. 13. The third brush bears between the two north poles at the neutral point formed by the gap between them.

To obtain independent regulation for each branch it was found only necessary to strengthen one north and one south pole, those being the ones diametrically opposite, and weaken the other two, giving any required difference between the pressures of the two sides. This is easily done by exciting the opposite north and south poles by one circuit with a regulator in it, and the other two by a separate circuit with another regulator. Some difficulty was experienced at first by the tendency of a strong pole to reverse a neighboring one of the same polarity. This was overcome by crossing the exciting circuit so that one pair was excited from the circuit in which the pressure was generated by the other pair and vice versa. This made it impossible for one set to come up to strength without both coming up. A 75 K. W. machine of this type was run for some time at the Berlin Exposition in 1896, with the frequent occurrence of 200 amperes on one side and 400 amperes on the other, without any noticeable change in the working of the machine.

This type of machine requires a little different design from the usual multipolar on account of the change in the magnetic path. The armature requires about twice the iron for the usual type and the yoke between N. and S. poles needs twice the cross section, as it now has to carry all the lines of force due to one pole piece. But there is no use for any iron between the two N. or between the two S. poles, except for appearance and mechanical strength. In this machine it is essential that only one neutral brush be used, for if another were placed opposite the first and connected to the neutral, the independent regulation of the two sides would be lost.

For general discussion of the three-wire system see the following:

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F. B. Crocker, Elec. World, vol 29, p. 126, et seq., 1897.

A. V. Abbott's Electrical Transmission of Energy, p. 423.

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(1). Crocker Elec. World, Vol. XXIX., p. 126, 1897.
(2). Crocker Elec. World, Vol. XXIX., p. 237, 1897.
(3). London Elec. Rev., Vol. XXXVI., p. 805, 1895.
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(5). Electricity, Vol. VIII., p. 310, 1895.
(6). Proc. Institute of Electrical Engineers (England), Vol. XVII., Nos. 72 and 73.

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(8). Patent No. 360,125.
(9). Patent No. 468,122.
(10.) Patent No. 460,364.
(11). Elec. Engineer. N. Y., Vol. XIII., p. 572, 1892.
(12). London Elec. Rev., Vol. XXXIV., p. 146.
(13). Elec. World, Vol. XXIX., p. 32, 1897. Am. Electrician, Vol. IX., p. 21, 1897.
(14). Elec. World, Vol. XXIV., p. 505, 1894.
(15). London Elec. Rev., Vol. XXXIV., p. 624, 1894. La Lumiere Electrique, Vol. LI., p. 30, 1894.
(16). Zeit. f. Elek., Feb. 1, 1897. Elec. World, Vol. XXIX., p. 265, 1897.
(17). Elec. World, Vol. XXVIII., p. 569, 1896. Elektrotecknischer Zeitschrift, Vol. XVII., p. 611, 1896.
(18). Elec. World, Vol. XXVIII., p. 569, 1896. Elektrotecknischer Zeitschrift, Vol. XVII., p. 611, 1896.

RECENT RAILWAY ECONOMIES.*

E. E. WOODMAN, C. E.

A late news item recounted the discovery of a burning coal bed in Wyoming, and there is little doubt that the incident was only the most recent of many re-discoveries of the same thing that I saw at the head of Little Powder river thirteen years ago, when examining the Black Hills country for a railway line and to report on its natural resources. At that time the geological insularity of the Hills, as an outlier of the Rocky Mountains, was matched by the isolation of the people, who were two hundred miles from the nearest railroad, possessed of a Sancho Panza's Island in the midst of the Great Plains. I went a hundred miles west of Deadwood with a guide, riding in a light buckboard, to examine an exposure of lignite. We found the half-formed coal showing twenty feet of thickness, where a creek had made a shallow valley, and at this deepest place it was on fire and had been burning an indeterminable time. We fried our bacon and boiled our coffee on the glowing edge of this Inferno, and as I lay at night on the ground, with feet to the heat, in the midst of a vast solitude, and looked up to a few friendly stars, whose acquaintance always relieves me from the sense of loneliness when in uninhabited places, and somehow co-ordinates the universe, it was not impossible to guess at the grand scale of those operations of nature that resulted in this enormous bed of fuel. The old cosmogony, of which man and his home were the center, would have made all this for the very purpose of comforting the vagrant engineer. But Galileo, with the first feeble telescope, pierced that fog of error and proved that finite relations and adaptations do not really make clear any designs of the Infinite. But here was this exposure of lignite, five hundred miles intermediate between two similar beds known on the Northern Pacific and Union Pacific Railways. It was then a probable inference that it extended across the entire one thousand miles, and this opened broadly to the mental view the state of that young world in which peculiar and adequate causes were effective to such vast results.

The geologist and the chemist have delighted us with the natural history of a lump of coal. Igniting it as it were by the fire

*Lecture before the Society of Engineers, March 26, 1897.

of the imagination, they have made it glow for us with the light and the heat of a sun "before time was," of ages long antecedent to man, the clock-maker. They have clothed that ancient globe with a luxuriance of vegetation far surpassing the tangles of the Amazon, peopled it with corresponding animal monsters; and when I broke out pieces of the lignite in which the bole, the knots, the bark, the grain of the wood, were almost as palpable evidences of the tree as like parts would identify the allied tamarack of to-day, the vast swamps in which this immense deposit of half carbonized wood accumulated were conceived with the same strength as the ancient civilization of the Nile Valley is now apprehended, when we look upon the photograph of Rameses, the very Pharaoh who persecuted the Hebrews. The imagination has indeed notably played its part in science. It is a kind of sublimated reason, by which truths now beyond the range of demonstration are gained by a leap and held till the slower faculty can slide a cantilever over the gap. It has also been a powerful instrument of invention, and the chief aid in effecting those ameliorations of the physical conditions of life in our world on which all other forms of progress depend. Doubtless the cave dweller brooded over the problem of how he could subdue the mammoth and make it carry wood for his fire. For in after ages he accomplished it in India, meantime improving his weapons and tools from flint to copper, to bronze, to iron, to steel, ever further subjugating the hostile forces of the world. With the rise of intellect brute forces appear more and more to have declined, as if man was ever the integration of all that had gone before; though far weaker physically, yet able to cope with the same obstacles by a higher method, which we may typify by the lever. In due time he thought out his steam engine, by which he brought back the mighty saurians, harnessed them to tread-mills the world over, and trained pterodactyls to fly in lines at fifty miles an hour, pulling the limited. And so we come to our theme of the railroad.

Next to the invention of the steam engine, that of the railway has done most for our material welfare; and next again the Bessemer process, by which both of the others have been so vastly amplified in their utilities, may be given rank. Using this term to cover all the improvements by which steel has been made so much better and cheaper, we may affirm that the enormous increase of wealth shown by many countries, including our own, is primarily due

to the success of this invention, of which it was long since said: "It has been of more value than all the gold of California." In forty years our constructive arts have been revolutionized by it. Whereas, forty years ago, iron was too costly and unreliable to be much used by the engineer, and steel was entirely beyond his reach, twenty years since the new metal had not only superseded iron for most constructive purposes, but at a saving to mankind of five thousand millions of dollars, computed on the total product and the diminished cost. To the date of this invention we refer the introduction of improved heavy machinery, steel vessels, heavy ordnance, armor plates and modern projectiles, the widespread use of rolled forms in architecture and bridge construction; while it would be well-nigh impossible to enumerate all the present uses of steel, which from its superior strength and ductility, comparative lightness, uniformity of quality, and adaptability to special requirements, has finally almost driven iron from the engineering field. The most admirable and useful point of difference between this metal and iron is, that the fibrous structure of iron has in steel given place to a homogeneous molecular arrangement, so that, as Sir William Siemens described it, "it has its full strength in every direction."

The most extensive and useful application of the Bessemer metal has been in the improvement of railways, chiefly in the track, though otherwise largely in the related structures of bridges and buildings, and in machinery and rolling stock. The locomotive was the first essential of a steam railroad, the track the second; but soon these conditions were reversed, the track having become the more difficult to maintain with the requisite economy. The Rocket weighed 2½ tons, our present engines weigh 60 tons. The former carried 2,500 pounds on each driver, the latter carry over 20,000, and these differences are a fair index of the economy of using steel. Since the introduction of this material the improvement of our railways, the great increase in their mileage and the corresponding development of our national wealth have severally been very great, and may be traced to the possession of this metal. The tendency of railway economies along mechanical lines during the last twenty years, by which these results have largely been obtained, has been controlled by the Bessemer process.

The first Bessemer rails introduced into this country from England cost one hundred and fifty dollars a ton. Like rails of our own make have recently been sold at seventeen dollars a ton. Sir Henry himself, while in the first flush of his success, and amassing a fortune, immediately reduced the cost of tires in England from four hundred and fifty dollars a ton to one hundred. A Bessemer rail will last from six to nine times as long as an iron one under the same traffic. Here is a clew to many economies. With the life of rails so greatly prolonged, the cost of renewal of rails and repairs of track, a heavy item of expense to every company, is of course greatly reduced. From being able to obtain rails at once cheaper and far more durable, other important consequences have flowed. Heavier rails have been placed within reach. This in turn has made possible the use of heavier engines, stronger cars and heavier loads, resulting in such economies of operation as to be a principal cause of the continual decline in freight rates in this country, which to-day are only a third of what they were when the new metal had become fairly introduced.

If an engine of new model proves to be twice as serviceable in tonnage hauled as one of the kind previously used, then half as many trains, drawn by such new engines, will do the same business. This will chiefly apply to through traffic, because local traffic usually does not make long trains, or at all events the same degree of economy can not be worked in it, since heavy engines can not so frequently be loaded to their full capacity in local business as in through traffic. The most obvious reduction in expenses due to the new engines will be, a certain number of train crews dispensed with. Also, there may be economy in fuel, the general rule being that large boilers and engines use fuel to better advantage than small ones. I may illustrate this by recent experience. The freight traffic of the C., St. P., M. & O. Railway Company during October, 1896, was the heaviest in the history of the road. As a consequence of this, engines were loaded to their full capacity, and the engine performance became especially interesting. Following are the mileage and coal consumption of three classes of engines:

Cylinders.	Miles run.	Tons coal used.	Pounds coal. per train mile.
17 by 24	133,750	6,245	93.4
18 by 24	149,400	6,853	91.7
19 by 24	54,664	3,014	110.3

It has not been practicable for me to obtain the tons hauled by these engines. But assuming that they were fully loaded, which we may do in consideration of the deficiency of cars under the unusual demand, a comparison of these engines in respect to consumption of fuel may be reached by dividing the quantity of coal consumed per train mile by the adhesive weight, or weight on the drivers, since this weight is closely proportional to the hauling capacity, and in the present case to the number of tons hauled. Applying this test, we find that the relative consumption of coal per ton mile is, for the 17 by 24 cylinders, 20; for the 18 by 24 cylinders, 16; for the 19 by 24 cylinders, 11; or, the largest shows an economy of 45 per cent over the smallest in the item of fuel consumed per ton mile.

Another illustration may be drawn from passenger service in the same month. The new express locomotives used on the Chicago limited have cylinders 19 by 24, drivers 73 inches, and weigh 126,000 pounds each. The engine and tender and supplies of fuel and water weigh 113 tons. If we add to the last mentioned weight the weight of the cars that compose one of these trains, and of the several items comprised in the load, we shall find that the average number of tons moved per train mile is 456. In October, 1896, twin engines in this service together ran 17,015 miles and consumed 746 tons of coal. From these data it follows that these engines moved a ton a mile by the consumption of 19-100 of a pound, or 3 ounces, of coal. The card time of this train, covering a distance of 200 miles, is 31 miles per hour, and the actual speed between stations often 40 to 50 miles.

In comparison with this we take the Stillwater run, with engine and tender weighing 58 tons, and cars 57 tons. These trains made 5,840 miles in October, with the consumption of 170 tons of coal, showing that it required half a pound of coal to move a ton a mile, or 8 ounces as against 3 in the case of the limited, and at lower speed. Part of this difference is undoubtedly due to the relative preponderance of engine friction in the second case. It is no doubt true that the lighter engine could take a heavier load and yield a better result per ton mile than it did in this case.

Three ounces of coal seems a small quantity to move a ton a mile by any kind of mechanism, yet it is well known that the locomotive is a form of engine comparatively wasteful in the use of fuel. Bituminous coal is used in operating the trains under

consideration, Spring Valley, from Illinois, in running north, and No. 8 Pittsburgh, from Pennsylvania, in running south. For the purpose of illustrating fuel economy,I have selected a distance of 4.55 miles in which no stops are made by these trains, the time allowed being seven minutes with the grade and eight against it. The average speed is 36½ miles per hour, and the average of the rise and fall 66 feet, corresponding to a grade of 14.5 feet per mile for the whole distance. I neglect the effect of a little light curvature. Using Clark's formula for train resistance, and comparing the foot-pounds exerted by the engine in moving a ton a mile under these conditions with the stored energy in the 19-100 of a pound of coal consumed in that service, it appears that 7 per cent of the stored energy of the fuel is converted into useful work. By the Searles' formula a very much higher economy is indicated. But the 7 per cent is itself an improbable value. Working tests skillfully planned and carefully made, of equally good non-compound engines, showed only 5½ per cent of the theoretic value of the fuel realized. Moreover, the 7 per cent comes too near the performance of the best stationary engines. I am indebted to Mr. J. D. Estabrook, C. E., for the result of a seven days' test of the triple expansion Schichau engine of 1,100 horse power now in the Washburn-Crosby Company's flouring mill at Minneapolis. This fine engine will be remembered by many who saw it in operation in Machinery Hall at the Columbian Exposition. The test was conducted by the late Prof. Wm. A. Pike and Prof. H. E. Smith, both of this college, and showed one indicated horse power for 1.928 pounds of Youghiogheny coal consumed, the coal having a determined calorific power of 13,222 B. T. U. Thus the engine developed in the cylinders 10 per cent of the theoretic value of the fuel. Deducting one-tenth from this result for engine friction, we see that no single expansion locomotive can be held to realize 7 per cent. economy without supposing that it comes well up to a triple expansion stationary engine in efficiency. I think the principal source of error here is not in the calorific value assumed for the fuel, but in the formula for train resistance. For high speeds both those named appear to give excessive results. Consequently, when we use either for high speed, the engine appears to be doing an amount of work that in reality it can not get out of the coal. So the above approximation of 7 per cent net out of the fuel is only to be considered as suggestive, or as possessing a negative

value in that it impugns the traction formulae. In order to reach a result of greater value, conditions that I have assumed, such as the calorific power of the fuel, and the traction force exerted, would have to be determined by experiment.

However, as a rough check upon the foregoing, I cite the performance of English freight engines, as given by Mr. D. K. Clark, in his elaborate treatise on the steam engine, one of which moved a ton a mile by the consumption of 16-100 of a pound of coal and another 14-100. Of course the speed was here much lower, and the coal almost certainly better, and we have no account of the grades. Also, the Scotch Express, which makes about fifty miles an hour on the average, and mounts some long and heavy grades, is drawn by a compound engine that moves a ton a mile with two ounces of coal estimated to be fifty per cent better than ours, though it can not be so much better than the coal above described. Again, the freight train statistics of the C., St. P., M. & O. Railway Company for the years 1885 and 1895 show that the average performance of engines in each year was to move a ton a mile with 19-100 of a pound of coal. These results are based on the consumption of coal per mile run of engines in hauling 796,000 cars in the earlier year, and 978,000 in the later one, and therefore are deductions in which all kinds of train resistance are averaged.

But cost of fuel is only one item of engine expense, and heavy engines are costly in other ways. The repairs upon them are usually very expensive. Their fire-box plates are so severely tried by the fierce combustion, and by expansion and contraction, as to require frequent renewal. Strenuous endeavors are made to secure the best material for this purpose, yet a sheet has been known to show more than a hundred and fifty cracks after a short service. Also, the great weight of the reciprocating parts aggravates the destructive effect of a lack of balance in those parts, and consequently these monsters soon pound flat places in the tires of drivers, and must be sent to the shop to have those defects turned off. Their effect upon the rail will be mentioned later.

An increase in the capacity of freight cars has kept pace with the growth of engines, the two are correlatives of a single development. This increase has worked an economy in heavy traffic because less dead weight proportionally is hauled. A car

weighing 20,000 pounds carries 20,000 pounds; one weighing 22,000 carries 40,000; one weighing 29,000 carries 60,000. From 1865 to about 1876 nearly all freight cars were of the capacity of 20,000 pounds. The increase then began. On the road of which I have been speaking the average capacity of the freight car has increased twenty-five per cent in the last eleven years. But the Lake Shore and Michigan Southern, by the fullness of its reports, offers one of the most striking and useful illustrations of this economic tendency. This is a trunk line, so called, one of the main routes of traffic between the East and the West, on which the pressure of competition would naturally give a powerful stimulus to mechanical and engineering ingenuity. Also the movement indicated has been so long in operation with this company that it may be measured by results. Accordingly we find that the freight traffic of this road shows a growth in ton miles, between 1870 and 1895, of 318 per cent, due to an increase in train mileage of only 80 per cent, but in train loads of 132 per cent. The car equipment of this road also throws light on these changed conditions. Out of 18,700 freight cars, 5,700 carry 40,000 pounds each, 3,200 have 45,000 pounds capacity, 3,200 have 50,000 pounds capacity and the remaining 6,600 are of 60,000 capacity. Many roads have special cars designed to carry exceptional loads. The Pennsylvania and the Northwestern have a number whose capacity is from 70,000 to 150,000, but these are not sufficiently numerous to further emphasize the tendency towards heavier loading. Nor is it likely that the movement will go further in the near future. Indeed, a reaction has already set in. Some managers have discovered the limited use of cars of great carrying capacity. Such cars are in fact only suited to heavy through traffic, and a company may make the mistake, and some have made the mistake of putting too much money into this kind of rolling stock. A car of 50,000 pounds capacity, found in a local train, strutting as it were with a few boxes of soap, is an example of pride going before a fall, it is losing money for the company. The equipment should be adapted to the traffic. One source of loss in these cars of large capacity is that, especially on foreign roads, they stand idle a great part of the time because no suitable loads are offered.

In connection with the subject of dead weight, the steel car is likely to work an economy. One of these cars, that weighs 25,900 pounds, carries 80,000 pounds, as compared with a wooden

car of the same weight that carries but 50,000 pounds. The principal objection made to this car is the conservative one that it is apt to prove costly to handle and repair after it is wrecked. But this implies that the accident is the rule and not the exception in car service. The objection may be overcome, and doubtless will be overcome, by improvements in design, whereby such cars can readily be taken to pieces. Then they may easily prove to be more economical in repairs than wooden cars, which so often are destroyed as to all but the iron in them.

With fewer trains passing over the road by reason of using more powerful engines, renewals of track repairs may be less costly. In short, out of a total of forty items of operating expenses, sixteen will be favorably affected by such a change to heavier engines, and many more will not be affected either way. On the other hand there is to be charged against the improvement the increased cost of engine repairs and the interest cost of making the change in engines, track and bridges. Though the last two would by some companies be deemed betterments, and their money cost would be added to the cost of the road, yet interest on the amount must be earned if the assumed economy is justified. This is the general principle by which all such experiments are to be measured. For all our railroads have been built with borrowed money. The main end of the operating department must be, to earn interest on the bonds and a reasonable dividend on the stock. It is primarily the volume of traffic that does this, supposing, of course, that the business is conducted at a profit. Any specific economy in operation will bear usefully on this result, but is of secondary importance compared with the volume of business. That this is true is shown by the fact that any particular economy, such for instance as the introduction of more powerful engines, will usually not be obvious on examining the general published statistics of most companies. Thus, it might be expected that the effect of introducing heavier rails, with heavier engines and cars of greater carrying capacity upon them, would immediately be seen in the items of renewal of rails, cost of repairs of track, of repairs of engines, and in the percentage of operating expenses to gross earnings. But with a successful road fifteen hundred miles long such anticipated results will not often be realized; that is, the general statistics will not disclose the particular economy. And it is for the reason that the relatively

small results are lost in the magnitude of the totals. They have, so to speak, only local bearing and significance. The accounts of the division on which heavy engines have displaced light ones may show that expenses have been reduced by the change in a degree justifying the experiment. But after all it is a complicated matter to balance the account between certain visible and incontestable savings, such as come from employing fewer engineers and firemen, and from a smaller consumption of coal in moving a given tonnage, on the one side, and on the other not only interest on the cost of additions to the property, but some expenses not at first readily determinable; as, for instance, whether the big engines will not pound themselves to pieces much faster than lighter ones, and whether they will not file away the rails and their own tires much faster than the others did. However, during the past twenty years the movement has been in the direction indicated, and so far as cost of rails is concerned is sustained by some general considerations.

If the weight of rails were to be increased from sixty-five pounds per yard to eighty, with corresponding fastenings, the increased cost of track at the present time would be about $1,400 a mile. If, on a division two hundred miles long we add $20,000 to this for alterations in bridges, to enable them to carry the heavier loads, we shall have a total of $300,000, the yearly interest on which, at five per cent, would be fifteen thousand dollars. Now, such a division may be earning $3,000,000 annually, on which the interest charge for account of improved track, as above given, would not be a burden, even in the extreme case that the heavier metal did not prove economical in connection with the heavier rolling stock. But on the other hand it may almost be decided without going into details, that an economy of $15,000 a year can be worked in operating expenses amounting to $1,800,000 by the purely administrative reforms continually being introduced. Thus there is a margin of opportunity for the experiment; besides which are the possibly longer life of the rail, fewer track repairs, the saving in fuel on the large engines, and in the wages of trainmen, leaving some other items doubtful. So far then as this movement has proceeded, it seems to be justified by general prudential considerations.

The further question arises, what is the rational limit of this economy? How long can we go on, increasing the weight of

engines and cars and loads on the present quality of metal? The chief limiting fact would seem to be the ductility of the rail. It will not do to use a brittle rail, but on the other hand the soft steel now used flows under the cold rolling given it by the heavy wheel loads. Rails give out partly by wear and partly by deformation. On the outside of curves they are rendered unserviceable as much by the latter cause as by the former. In some of the new engines each seventy-three inch driver presses on the rail with a weight of over 20,000 pounds, and it was shown by Mr. Chanute's experiments that with 14,000 pounds on a five-feet driver the small area of contact indicated a pressure in excess of the elastic limit of the steel. So also these great machines, with the larger wheels but heavier loads, are certainly very destructive of the rails, first by grinding them, and again by squeezing them out of shape much in the manner that they were originally shaped. These results may easily be observed in large yards, where the inside of many rail-heads will be found worn away to the splices, the outside of them showing at the same time a projecting lip formed by excessive pressure. It is obvious that increasing the depth and weight of the rail has its principal effect in strengthening it as a girder, to carry the load from tie to tie, and does not prevent the head from yielding outwardly under pressure. Therefore we must proceed cautiously if we further increase the load on the rail, carefully balancing the account between maintenance of way and movement of traffic. This may involve a more minute distribution of expenses than has been customary heretofore. On the Lake Shore road, before mentioned, the item of renewal of rails is about one per cent of the income. Expressed in dollars it is a large sum, but the small percentage shows that wear of rails is not a place in which large economy can now be hoped for. It is the place where expense is most certainly proportional to use, since it depends almost wholly on the number of trains run over the rails. There is therefore less chance here for waste or extravagance than in any other branch of operating expenses.

Supposing the limit to have been now nearly reached in adapting the weight of engines to Bessemer rails, I think we may look to see future economies take one of two directions. The first is in the line of a better rail, either of steel possessing greater durability in this kind of service, or of some alloy offering higher resistance to wear and distortion than this steel, yet sufficiently

ductile to be rolled and to prevent brittleness. Our ordnance officers are dealing with a similar problem, namely, to increase the power of guns without increasing their weight, for which they need a metal for the inner barrel that will resist the erosive action of gases at high pressure better than the steel now used is found to do. The invention of Bessemer metal was due to Sir Henry Bessemer's desire to obtain a better metal for ordnance. He knew little or nothing of metallurgy when he began his experiments, which resulted in revolutionizing the steel industry of the world. It is therefore not unreasonable to expect that a better rail, for which there will be, perhaps for ages, an ever increasing demand, will be forthcoming. Bessemer rails, superior as they are compared to iron ones, may yet be the first windfall of a tree that is to yield better fruit. As a mere hint, I may allude to the possibility of cold-rolling the rails in manufacture.

The other direction in which I think we may look to see economy operate, on the supposition that wheel loads are now at a profitable maximum and that we must continue to rely on our present rail material, is in the use of more frequent but lighter and faster trains. The problem always is and will be to administer a railway most profitably. Accordingly, we must keep in view the fullest utilization of the property and not lose sight of the fact that an idle railroad not only is earning nothing, but is decaying and disintegrating as a physical structure. When we reflect on how small a part of each day any particular rail in the line of this vastly expensive railroad actually is used in transportation, and earning something, the possibilities of traffic enlarge upon us. We then see the bearing of the idea of trying to work economy by more and faster trains in place of fewer and slower ones; of thus securing a greater average daily movement of freight cars, now surprisingly low; in short, of making time more an element of profit throughout the service, as now it only is in respect to passenger trains, to some few articles of perishable freight, and to the carrying of cattle. A street railway in a populous city illustrates the opposite tendency to that observed in recent steam railway management, for there we see cars or trains in sight one from another, the rails kept almost continually warm by the friction of use, thus realizing the foregoing ideal of a productive property. Circumstances have made our practice very unlike the European in respect to train service, but I think

we may look to see changed social conditions, due to denser population and a fall in wages, bring in a similar economy.

Among the most remarkable facts of our subject is the constancy of the ratio of operating expenses to income on railroads in general. On the Lake Shore and Michigan Southern the average for the last twenty-five years has been 65 per cent, with but one very marked fluctuation. On the Chicago, St. Paul, Minneapolis & Omaha Railway it has been practically stationary at 64 per cent for the last fifteen years. On the first mentioned road the economies that we have outlined were long ago in full operation, on the latter they are not yet so completely developed. These facts seem to show two things of interest: First, that the proportional cost of operating a particular road is remarkably constant under all circumstances; and, second, that all railway improvements, not only betterments, but also those which make for economy of operation, inure to the benefit of the public. The most prosperous roads have only paid interest on their bonded debt and a fair dividend to stockholders. All the rest of their earnings have gone to the public, largely in the way of improved and cheapened transportation. I think we may infer from this stability of the relation of expenses to earnings that fast, light freight trains may be substituted for slow heavy ones without loss to the companies, but with a growing profit due to more rapid circulation of commodities; and that this will prove true, notwithstanding the theoretical, and indeed actual cost of increasing speed.

Another direction which economy of operation has recently taken is toward loading engines to their full hauling capacity. Until within a short time the rule was to load them with the number of cars that the engineer said he could take up the limiting grade. This made the rule sometimes coincide with the caprice of the engineer. If on approaching the ruling grade he told the conductor that two cars must be dropped, they were accordingly set on the siding, to wait there till some other engineer would not rail at the suggestion of picking them up. While this system was in operation, an examination of way-bills often disclosed that the number of cars in the train was sufficient fully to load the engine if the cars had been fully loaded, but that in reality the train load was far too light for the engine because of cars very lightly loaded. All this has now been changed to great advantage by adopting

what is called tonnage rating. Under this system the traction of locomotives has been determined experimentally and the proper loading has then been derived from the results. To this end a freight engine is tested on the controlling grade of each of the sections into which the division is naturally divided by the existence of such grades. This engine is run up the grade at a proper speed, say 12 miles per hour, with a sufficient number of loaded cars of various known weights to stall it. Then an assistant engine goes behind and helps the train to start up again and acquire a speed of five or six miles an hour, when the helper drops off with one or two cars, and thus another trial is made, and so on till the load in tons that the engine can surely take up the grade is practically determined. On each hard spot in the division, caused by grades or by grades and curves combined, the engine is similarly tried; and then small deductions are made from the maximum loads so found to allow for specially long grades, such as tax the steaming capacity of engines.

An engine having been thus tested on the governing grades, and its performance recorded, one engine of each of the remaining classes in service is then tried similarly on one or two of the same grades and its relative power thus determined. This relative performance affords the rule for loading engines of these classes proportionally to their developed capacity. Thereafter all loading is by tons instead of cars.

In preparing the rating sheet to govern engineers under this system, some superintendents make three ratings, corresponding to three assumed conditions of weather and rail, while others rely on the discretion of the engineer to make deviations from the printed single ratings based on the trial conditions, at the same time holding him accountable for satisfactory engine performance. The tons hauled and coal consumed by each engine are bulletined monthly, and the engineers are found anxious to make good records by hauling full train loads. The economy thus effected is considerable. It has increased the train load from ten to twenty per cent on several roads whose officers have kindly given me their results.

Still another way in which economy has been worked in recent years is by reducing grades and curvatures. Most of our Western roads were originally located with an eye to facility and economy of construction, by the eye of the promoter rather than that of the

engineer. They were what is called surface roads, conforming closely to the slopes of the country with their grades, and to the plan of the hills with their curves. Heavy grades and sharp curves and combinations of both marked this era. Many companies have recently spent large sums in improving these defective pieces of alignment, which were originally due to poverty of resources, and did not reflect on the intelligence of the engineer. To reduce a maximum grade is equivalent to increasing the capacity of engines. The equation is between the cost of operating the line as it is, and interest on the cost of the improvement, and as to all very bad places there can be no doubt that the betterment will be justified by events. It is largely by such works as these that lines geographically well placed are making their future prosperity secure against the competition of inferior lines, while by the same stroke they are reducing the cost of service to the public.

But of all causes that have contributed to economy of operation, the consolidation of short lines into large systems has been the most effective. Twenty years ago a thousand miles under one management was a giant railway. Now we see from five thousand to eight thousand miles in one system, often practically controlled by a single administrative officer. Such a combination of interest and of utilities has reduced order out of chaos, established long periods of peace where there was continual war, and has given greater stability to private enterprise in the districts so served, because such a great system possesses an inertia comparable to that of a planet in its orbit, which hardly any force can disturb. The result is a development peculiar to this form of human activity under freedom. Under free competition the result is what we see, what no man could have foreseen or forestalled: it is that we have the best and cheapest service in the world.

I omit many minor economies, only intending to present a broad outline. It is for you who are soon to take possession of the field of engineering to be alive to the opportunities and requirements of this so learned profession. We have an enormous country, nearly the whole of it still undeveloped as compared with the wealthiest parts of Europe. We have one mile of railroad to eighteen of area, as compared with one to less than four in Belgium. Our mileage is almost sure to be doubled in your

lifetime. Yet this is only one branch of engineering and each of the others presents as wide a prospect. There is therefore every incentive to your ambition. You have but to read the story of Aladdin as a parable. Every man is born with an enchanted lamp of mental aptitudes. His fortune depends on his keeping it burnished.

As a last word, I should like to lodge in your memory the counsel of one of the great men whose names adorn the roll of the profession. Tyndall was a practicing engineer before he shone out as a philosopher. Speaking of his having failed in tens of thousands of experiments to wring a certain truth from nature (a struggle in which, however, he was finally successful), he gives this advice to young men:

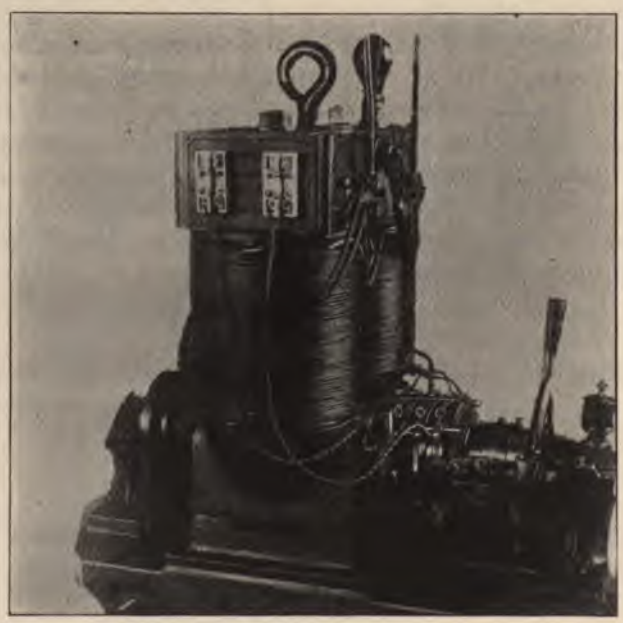
"The experimenter, and particularly the young experimenter, ought to know, that as regards his own moral manhood, he cannot but win if he contend aright. Even with a negative result, the consciousness that he has gone to the bottom of his subject, as far as his means allowed—the feeling that he has not shunned labor, though that labor may have resulted in laying bare the nakedness of his case—reacts upon his own mind, and gives it firmness for future work."

A MULTIFUNCTIONAL DYNAMO.

GEO D. SHEPARDSON, M. E.

The Edison dynamo in the electrical engineering laboratory of the University of Minnesota is an interesting example both of the expedients to which one may resort in teaching with somewhat limited appliances and also of the manifold value and flexibility of electrical machinery.

This machine was purchased in 1887 for the purpose of lighting the Mechanic Arts Building and for supplying current for the



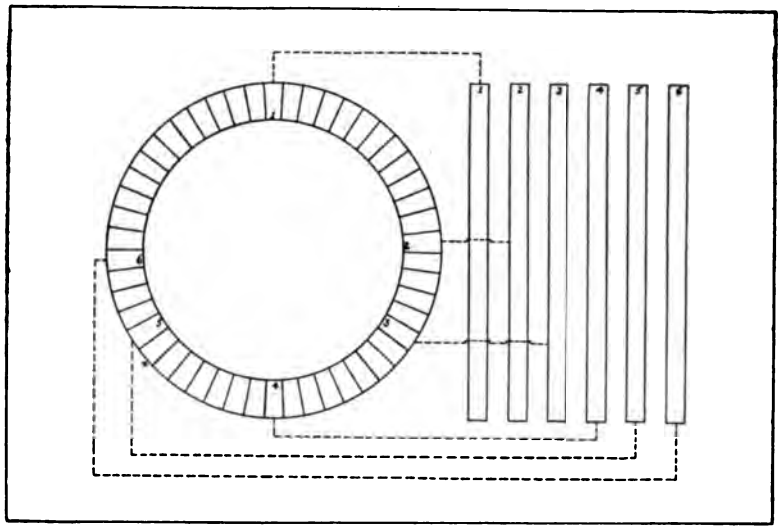
physical laboratory, which was then located in that building. In 1891 it was moved to its present location. It has been in operation for an average of probably two hours each day during nine months of each year and has cost nothing for repairs except one set of brushes, two turnings of the commutator and one re-babbetting of the boxes, costing in all about eight dollars, or less than one dollar per annum. The machine seems to be as good as new and more valuable than at first, its attachments overbalancing the great

reduction in prices of recent electrical machinery. This machine, part of which is shown in the accompanying halftone engraving, has been equipped with eight series coils having individual terminals for coupling in various combinations, with a series resistance to ease starting as a motor, with two switches for short-circuiting either the series resistance or the series magnet coils, with six collecting rings and brushes for obtaining single-phase, two-phase and three-phase currents, with a field exploring wire and instantaneous contact device, and with divided segments for voltage distribution measurement by single or two-brush methods.

By various combinations of switches on the machine and at the switchboard, this machine may be operated as a shunt, cumulatively compound or differentially compound motor, or as a dynamo either singly or in multiple with the Mather machine in the Mechanic Arts engine room over four hundred feet away. When the Armory is lighted, these two dynamos are operated on the three-wire system, the lamps being nine hundred feet from one dynamo and thirteen hundred feet from the other. A similar condition exists when the Library and Chapel are lighted simultaneously. It thus happens occasionally that on a single day the Edison machine is driven as a motor by the Mather machine to operate the line shaft of the laboratory, later is driven by the laboratory engine and operated as a dynamo in parallel with the Mather machine to help carry the afternoon lighting load in the shops and library, and then in the evening of the same day is operated as a dynamo in series with the Mather on the three-wire system of lighting the Armory or the Library Building. The installation of a larger direct connected unit in the lighting plant during the coming summer will obviate the necessity for this varied use except for demonstration purposes. By the recent addition of six collecting rings, the machine is available as a rotary transformer, changing the direct current from the Mather machine into single, two or three-phase alternating currents. When driven by belt, it will operate as a self excited alternator for giving any of the three alternating currents or for any combination of them; while delivering continuous currents at the same time. By taking account of the various possible arrangements of the series and shunt coils, a list of several hundred arrangements and uses of this truly multi-functional dynamo might be enumerated.

A few points in the mechanical construction of some of the attachments may be of interest. As seen in the figure, the collect-

ing rings are mounted upon the armature between the commutator and the polepieces. In order to obtain a substantial support for the rings, the canvas cover was removed and the uneven space over the armature leads was partially filled with hard cord wound on as tightly and evenly as possible and then coated with shellac. After this had become thoroughly dry, it was covered with a number of layers of paper. Heavy manilla paper was cut into strips about an inch wide and five or six feet long. A number of these strips were soaked in water until quite soft and were then painted on one side with shellac. The strips were then wound over the cord back and forth until the whole surface was covered two or three layers



deep. This was then allowed to dry for twenty-four hours, during which time the paper shrunk and dried so as to be very hard and dry. Three layers more were then wound on and allowed to dry. In this manner the space was filled up to a size nearly equal to the outside diameter of the commutator. A tool rest was then made from a bar of iron one inch wide, one-quarter inch thick and about a foot long, by bending about three inches at one end at right angles and drilling two holes through the short end which was screwed to one of the polepieces in place of the fuse block. By the help of this temporary tool rest and a sharp diamond pointed hand turning tool, the hardened paper was turned down to an approximately true cylinder. A sheet of red fiber one-sixteenth

inch thick was then cut wide enough to extend from the back of commutator to the armature head and about six inches longer than the circumference of the paper surface. After being well soaked in water, this was bent around the paper surface and allowed to dry while held in place by twisted wire bands. When dried, the overlapping ends were cut obliquely at angles of about forty-five degrees and to such a length that when drawn tightly together the edges just met. By making the joint oblique rather than square, any tendency for the fiber to open out between the rings was overcome. Before the fiber ring was finally placed, strips of sheet brass one-sixteenth inch thick and three-eighths inch wide were prepared for connecting the collecting rings with the desired commutator segments. These were fastened by flat head countersunk screws tapped into the radial projections of the commutator segments. Grooves for the brass strips were cut in the paper so that the strips should be flush with the surface of the paper. Slits were then cut at proper places in the fiber ring, and the inner ends of the brass strips bent out so that when the fiber ring was drawn together, the ends of the connecting leads projected through the fiber. These were so spaced that the strip for each ring projected on the side furthest from the commutator, in order that in case of breakage the strip would still be long enough to fasten to the nearer side of the same ring.

The surface was then ready for the collecting rings, which were made from spring brush copper about three sixty-fourths inch thick and cut into strips one-half inch wide. These were cut from a wider strip in the squaring shears and were formed to approximately the right curvature in the rolls of a convenient tin-shop. Each strip was cut to the right length by trial and the inner side of each end was filed to a taper. A shim about an inch long was then cut from the same stock and filed to a corresponding bevel on each end. The shim and both beveled edges of the curved strip were then thinned and put in place, the shim being laid under the joint. The whole was then drawn tightly together by means of a No. 8 copper wire passed once around the ring and then drawn taut by block and tackle. When all was in place, the ring just touching one of the brass leads, a hot soldering bolt quickly made a strong splice an inch long, and made connection between the ring and the brass lead. After the six rings were made and put on in this way, they were turned off to a true surface by means of the rest pre-

viously used and a round nosed hand tool.

Brushholder studs were then provided by drilling and tapping a hole in each polepiece and screwing in a Bessemer steel rod eight inches long and three-eighths inch in diameter. The outer end of each rod was filed flat, to afford a grip for screwing it in by a wrench. Each brush-holder was made from a block of vulcanized fiber three-quarters of an inch thick, turned to a cylinder one inch in diameter, with two flat sides. A strip of spring copper was fastened to this by brass machine screws, to serve as a brush. A second strip of thinner copper was soldered to the first strip, so as to give two points of contact with each ring to avoid sparking. Longer machine screws serve to hold the brush-holders in place on the stud, also to raise and lower the brushes and to adjust the tension on the brushes. Copper washers, soldered into the slots in the screw heads, convert them into convenient thumbscrews. Short lengths of lampcord soldered to the brushes at one end and clamped in double-pole fuse blocks screwed to the iron name plates on the yoke, furnish convenient means for connecting with external circuits.

In order to obtain the proper spacing of the commutator to give the desired angular distance between various derived alternating currents, the commutator bars were numbered consecutively from one to fifty, as shown in the line sketch. From the rings connecting with bars numbered one and twenty-six, a simple alternating current may be taken. From bars thirteen and thirty-eight a second alternating current may be taken at right angles to the first. As fifty is not exactly divisible by three, it is not possible to obtain three currents exactly one hundred and twenty degrees apart, but this angle may be closely approximated by taking bars, one, eighteen and thirty-four.

THE MODERN EXPLOSION ENGINE.

E. S. SAVAGE, '97.

The great interest which is now being taken in this youngest of motive powers is strikingly shown by the large number of new makes of gas engines which have recently been placed on the market. In the United States alone over one hundred manufacturing establishments are building these engines, and thousands are sold each year.

The modern gas engine may in a legal sense be considered to have reached its maturity, as it is just twenty-one years since Dr. N. A. Otto first brought out his "Otto Silent" engine, which is the prototype of the majority of recent explosion engines. But though just outgrowing its infancy this young motor has made a name for itself which may well arouse jealousy on the part of our old friend "Steam Power."

It is to be understood that the term "gas engine" is generally used to denote any form of explosion engine whether the fuel is coal gas, gasoline or any hydrocarbon vapor. The uses and applications to which the gas engine can be put are numerous and varied in the extreme, and it would be difficult to suggest any application of medium power where it could not be profitably employed. These engines are now generally used for units of from ½ to 25 H. P.; the 4 or 5 H. P. being the size for which the demand is greatest. Gas engines of very much larger power are also in demand. Several manufacturers advertise single cylinder engines of 200 H. P., and there is now in operation at the Pantin flour mills in France a single cylinder gas engine which gives 450 indicated H. P., with illuminating gas as fuel, or 320 H. P. with producer gas.

Since gas engines have now become so numerous it is suprising to note the total lack of knowledge which exists among the great majority of people, regarding the principle of their operation. This is no doubt principally accounted for by the youth of the industry and also by the scarcity of books on the subject. When the time comes, which many believe is close at hand, when the horseless carriage will be a common sight on our streets, then the explosion engine will be more universally understood than the steam engine is now. Then it will be possible for a party

1 volume of gas to 5 vols. of air gives 96 lbs. in .05 sec.

If the compression is increased the maximum pressure will be increased in the same proportion. For example, if the mixture is 1 to 7 and the compression is 15 lbs. above the atmosphere, then the maximum pressure of explosion will be $(89+15)\ (30\div 15)=$ 208 lbs. per sq. in. absolute, or 193 lbs. above the atmosphere.

It is customary to compress the charge to about 45 lbs. above the atmosphere, causing a rise of temperature of about 280 degrees F. Higher compression is theoretically advantageous, but practical difficulties prevent the general use of compressions above 45 to 60 lbs. in most single cylinder engines. The mean pressure for the working stroke varies from 45 to 100 lbs. per square inch, depending upon the fuel, the mixture and the compression employed.

The pressures in gasoline engines are usually about 20 per cent greater than in gas engines. In oil engines the pressures are low, being about 30 per cent below those in gas engines.

The horse power obtainable from a single cylinder gas engine may be roughly approximated by dividing the volume of the stroke in cubic inches by 65, considering the speed as 200 revolutions per minute.

The power given with producer gas is about 75 per cent of that with illuminating gas, and the volume necessary is four times as great. An engine using producer gas requires very large gas ports.

The speed of gas engines ranges all the way from 100 to 1,000 revolutions per minute. The ordinary speed is 250 R. P. M. It is found that increasing the piston speed increases the pressure, quickness of the explosion and the efficiency.

In point of economy the gas engine is ahead of any other fuel consuming source of power. A consumption of 1½ lbs. of coal per I. H. P. is regarded as a very good performance for a steam engine even of large power. This means an actual thermal efficiency of 12 per cent, while 6 lbs. per I. H. P., or an efficiency of 3 per cent, is often considered economical. With gas engines an actual efficiency of 20 to 25 per cent, or a consumption of coal of 1.2 to 1.4 lbs per I. H. P., is a common performance.

D. Clerk states in a recent paper that the actual efficiency varies from 45 to 58 per cent of the theoretical, the theoretical ranging from 37 to 45 per cent. Gasoline engines consume

pressed and ignition occurs near the dead center. These engines are usually made in the upright form with one or two cylinders and are well adapted for boat propulsion.

The fuels commonly used with the explosion engine are: Illuminating gas, producer gas, natural gas, gasoline, kerosene and crude petroleum. Acetylene gas gives a very powerful explosion and will undoubtedly be used extensively when the calcium carbide is sold in quantities. Gasoline and illuminating gas are most generally used in America. Gasoline has the advantage that it can be used at any place and is very easily vaporized. In Europe oil engines are coming widely into use. Objections to the use of oil are: the necessity of some sort of heated vaporizer; the low mean effective pressure given during the stroke, and the liability of premature explosions in the cylinder. It is a curious fact that the vapor of heavy oils in contact with heated metal will ignite at a much lower temperature than light vapors and gases. This fact is utilized in the Hornsby Akroyd oil engine which ignites the charge in a chamber projecting from the cylinder head and is kept hot by the heat of the explosions.

To obtain an effective explosive mixture it is necessary to mix with the gas or vapor a volume of air containing sufficient oxygen for complete combustion. Owing to the burned gases contained in the clearance space, the ratio of air to gas is usually greater than that theoretically necessary. The ratio of the volume of gas or vapor, to air, giving the best results are: with coal gas, 1:6; gasoline vapor, 1:9; oil gas, 1:8. If the proportion of air used is too great or too small, ignition of the charge will not occur. The limits within which ignition is possible are: with coal gas 1:14 and 1:3, with gasoline vapor 1:17 and 1:2, with oil vapor 1:17 and 1:5.6. The ratio of air to gas necessary in any case depends of course upon the number of heat units which the gas contains. The average calorific values of the above fuels are: illuminating gas of 15 candle power, 620 B. T. U. per cubic foot; producer gas, 111 B. T. U. per cubic foot; gasoline vapor, 690 B. T. U. per cubic foot, or 11,000 B. T. U. per pound; light petroleum (sp. gr. .84), 18,400 B. T. U. per pound.

Nearly all gas engines are single acting of the trunk piston type with no piston rod. Objections to the use of a piston rod are: the difficulty of keeping the rod and the stuffing box sufficiently cool and the loss of energy due to the cooling effect of the rod

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burner are so adjusted that as the compression nears a maximum some of the fresh charge is forced back into the hot tube and causes ignition near the dead center. The advantages of this igniter are that it is easily managed by any one and not liable to get out of order. Its disadvantages are: the objection to the use of an external flame; the time required to heat the tube at starting, which takes from five to ten minutes, and the frequent renewal of the tube. Several English engines employ a timing valve, in connection with the tube igniter, which admits the charge into the tube just at the time for igniting.

The electric igniter, which is the one most generally employed in America, requires a battery, a self-induction coil and the igniter proper which consists of some form of make and break device in the engine cylinder. The battery must be long lived and easily renewed when exhausted. Eight or ten Salamoniac cells are often employed. The igniting spark is the spark of selfinduction, caused by breaking the electric circuit. No secondary wire is used, the spark coil consisting of a coil of insulated copper wire (No. 16) having a soft iron wire core. The igniter which can be made in a great variety of forms, is designed to make electrical connections within the engine cylinder and break the connection when explosion is desired. The contact points are often tipped with platinum to prevent corrosion. The igniter, battery, spark coil and a switch are all connected in series. The best form of electric igniter is that which gives a slow contact and a quick break, thus producing a long spark and avoids battering the contact points. The time of contact during which the current is flowing should be about one-twentieth of a second at the normal speed of the engine.

The temperature of the explosion of a mixture of gas and air is about 2,800 degrees F., or above the melting point of cast iron, which is near 2,000 degrees F. The maximum pressures commonly obtained range from 150 lbs. per square inch to 350 lbs. above the atmosphere. The maximum pressure with different mixtures of gas and air can be readily calculated, which gives the pressures obtained by explosion from atmospheric pressure, and also the time of the explosion.

1 volume of gas to 13 vols. of air gives 63 lbs. in .18 sec.
1 volume of gas to 9 vols. of air gives 69 lbs. in .13 sec.
1 volume of gas to 7 vols. of air gives 89 lbs. in .07 sec.

1 volume of gas to 5 vols. of air gives 96 lbs. in .05 sec.

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It is customary to compress the charge to about 45 lbs. above the atmosphere, causing a rise of temperature of about 280 degrees F. Higher compression is theoretically advantageous, but practical difficulties prevent the general use of compressions above 45 to 60 lbs. in most single cylinder engines. The mean pressure for the working stroke varies from 45 to 100 lbs. per square inch, depending upon the fuel, the mixture and the compression employed.

The pressures in gasoline engines are usually about 20 per cent greater than in gas engines. In oil engines the pressures are low, being about 30 per cent below those in gas engines.

The horse power obtainable from a single cylinder gas engine may be roughly approximated by dividing the volume of the stroke in cubic inches by 65, considering the speed as 200 revolutions per minute.

The power given with producer gas is about 75 per cent of that with illuminating gas, and the volume necessary is four times as great. An engine using producer gas requires very large gas ports.

The speed of gas engines ranges all the way from 100 to 1,000 revolutions per minute. The ordinary speed is 250 R. P. M. It is found that increasing the piston speed increases the pressure, quickness of the explosion and the efficiency.

In point of economy the gas engine is ahead of any other fuel consuming source of power. A consumption of $1\frac{1}{2}$ lbs. of coal per I. H. P. is regarded as a very good performance for a steam engine even of large power. This means an actual thermal efficiency of 12 per cent, while 6 lbs. per I. H. P., or an efficiency of 3 per cent, is often considered economical. With gas engines an actual efficiency of 20 to 25 per cent, or a consumption of coal of 1.2 to 1.4 lbs per I. H. P., is a common performance.

D. Clerk states in a recent paper that the actual efficiency varies from 45 to 58 per cent of the theoretical, the theoretical ranging from 37 to 45 per cent. Gasoline engines consume

about one pint of gasoline per B. H. P. hour. A small gasoline engine using gasoline, bought at retail, will equal in economy a steam engine using coal at $3.50 per ton and six lbs. per B. H. P. besides other savings as attendance, handling fuel, etc.

The advantages of a gas engine for electric lighting have often been pointed out. It is an interesting fact to note that if illuminating gas is used in a gas engine to run a dynamo, twice the quantity of light can be obtained from the lamps that would be given by burning the same quantity of gas in gas burners.

In closing it may be said that the present form of gas engine, notwithstanding all its advantages barely touched upon here, has many imperfections and there are yet many unsolved problems on which hundreds of engineers and inventors are now working. The gas engine has certainly a bright future before it and will ultimately displace steam in nearly all if not all small and medium power plants.

THE STRUCTURAL LABORATORY IN AN ENGINEERING COLLEGE.

FRANK H. CONSTANT, C. E.

Science, from its very foundation, has to do with the properties of matter. Its methods are inductive; its processes of reasoning, based upon observed phenomena of matter, lead to generalizations which, when sufficiently verified by physical tests, become part of the common stock of discovered law. The study of matter is the only accessible path to a knowledge of the laws of matter.

A first knowledge of the properties of matter was obtained accidentally by daily contact with the material world, and doubtless many crude scientists were thus developed. But at length scientists were no longer content to wait for accidental disclosures of the hidden things in nature. In the judgment chamber of the laboratory they have studied matter under many conditions and have learned some of its secrets. The marvelous advance in scientific knowledge during this century is mainly due to the development of the scientist's workshop—the laboratory. The laboratory has now become universally recognized as the only medium through which scientific investigation can be conducted.

Structural engineering is simply applied science. If the scientist is concerned with the laws of matter, to a greater extent is the engineer whose life is spent in battling with the forces which control matter. If the laboratory is necessary for the acquisition of scientific knowledge, its need is no less urgent to the engineer whose skill and success depend upon his intimacy with the properties of the materials with which he builds.

As in the case of science, engineering knowledge was at first acquired accidentally. If a structure, built largely by guess or rule of thumb methods, exhibited a disinclination to fail under a load, other structures of a similar character were built in like manner. This method for the advance of knowledge was costly, dangerous and slow, and under it structural engineering made but little progress.

With the advent of the iron age, mere experience was forced to give way to the more scientific methods of the laboratory. Timber, formerly the material almost universally used in structural

work, generally gives some suggestion of weakness when overstrained. On the other hand, if the material has been used too abundantly, an excess does not greatly increase the cost of the structure. With iron, however, the reverse is true. It fails with little warning, while excessive weight is prohibitive in cost. The engineer now studies his structure part by part, knowing that if the individual members are strong enough the entire structure will be safe. Thus the superior material has developed the laboratory, which, in turn, has reacted upon structural engineering to give it an impetus that could scarcely have been anticipated. Iron was adopted, at first timidly, then as its properties became better known, with greater confidence, only to be finally cast aside for a still better material.

But if the laboratory was necessary for the development of iron, its need is infinitely more real in the case of steel, whose properties may be wholly altered by the presence or absence of a fraction of one per cent of some impurity, or by a slight change in the mode of manufacture.

At the present time the testing laboratory is indispensable to the practicing engineer. Every large steel mill and bridge company, as well as many railroads, manufacturing plants, engineering firms and engineering colleges, possess well endowed testing laboratories. When engineers do not have convenient access to testing laboratories, they employ special engineering or inspection firms who have such equipment and are organized for this purpose, to test and inspect the material in the various processes of manufacture. Thus inspection has become a necessary part of structural engineering.

As familiarity with the properties of materials is as essential to the structural engineer as a knowledge of mechanical laws, so a training in the use, methods and results of the testing laboratory should form as vital a part of the course in an engineering college as the theoretical work of the class room.

The function of the laboratory in a course in structural engineering is four-fold.

First—To supplement the work of theoretical instruction in the class room.

Second—To acquaint the student with the common properties of the materials of engineering and with laboratory methods.

Third—To instill in him the spirit of original research.

Fourth—To form a medium for valuable contributions to the common stock of engineering knowledge by the publication of results in engineering journals.

In the class room the student is presented with theoretical principles and taught to use the knowledge of mechanical law thus gained in the designing of practical structures. In the laboratory he develops and verifies this theory for himself. Thus the primary function of the laboratory is to co-operate with the work of the class room and render this latter more fruitful. In this capacity the laboratory serves as an inspiration both to student and instructor.

In the laboratory the student also acquires a knowledge of the characteristic properties of the materials with which, in after practice, he will build his structures. This is by no means old ground, although the methods used may be well established. Two pieces of steel will not exhibit just the same qualities; yet from the generality of tests made under various conditions trustworthy deductions may be drawn. These tests, to be of any value, should be as nearly like those made by practicing engineers as possible.

But the engineer should not only know what his material ought to be, but what it really is. No engineer will allow material to enter a structure of any importance until a sufficient number of tests has been made to satisfy him that all of the material in that structure possesses certain approved qualities. Even the general properties of such a material as steel are constantly changing with the introduction of new and better modes of manufacture. The engineer who would seek the text books when writing a specification for his material, will find himself directing the use of iron after it has been supplanted by steel, or Bessemer steel when other engineers, who have kept in closer touch with the more recent progress of the mills, specify open hearth steel. Structural engineering is advancing with such rapid strides that he who waits for the carefully digested results of the experiments of others will always find himself just a little behind the times.

It is a necessary part of the training of the structural engineer to be able to enter the testing laboratory and make or direct a series of tests upon materials that he proposes to use in his structures. No laboratory instruction in a college which does not

give the student a real working knowledge of the laboratory methods of actual practice is inefficient.

Only a small amount of original research work can be conducted wholly by under graduate students, this being, perhaps, more profitably reserved for graduate students. Yet sufficient work of this nature should be prosecuted, under the direction of the instructors, to instill in the student the spirit of scientific research. This work should be chosen with reference to its practical character, and it should be conducted with such accuracy that the results may be a real contribution to engineering knowledge.

There is no more enticing field in engineering science than this one; and as yet it has not been much more than entered. Heretofore the efforts of experimenters have been directed to the examination of materials. But of late years more attention has been directed to tests of material after it has passed through one or more processes of manufacture into a finished structure.

These tests are of importance, as they determine into what forms and by what modes the parts of the structure may be shaped. From these tests the engineer learns to what extent material is injured by punching, what is the effect of annealing, how the strength of an eyebar compares with the sample piece, what is the strength of many kinds of riveted joints, what is the most efficient form into which a column may be built. An almost endless list of fit subjects for experimental examination could be named, some of which have already been studied, most of which have not, and nearly all of which will, from time to time, have to be studied anew, as the modes of construction and of metal manufacture change.

The present tendency is in the direction of tests upon a larger scale, upon full size parts of structures. Only a few of these problems can be mentioned within the scope of this article.

Perhaps as interesting a field for investigation as any is a fuller study of plate girder construction. The plate girder has now become the almost universal form of bridge for spans from twenty feet up to one hundred feet. It thus constitutes a large percentage of the total mileage of railroad bridges built each year. Yet the conditions involved in its design are uncertain and complex, and beyond the scope of theoretical treatment. Some of the prob-

lems to be investigated are: The real distribution of stresses in flange and web, the function, size and spacing of stiffeners, and the spacing of rivets in flanges, splices and stiffeners. In fact, nearly the whole subject of plate girder designing is wrapped in uncertainty. No doubt a clearer insight into the action of molecular and internal forces in matter will be of great assistance in the solution of these problems.

Another problem upon which so much has been done and so little has been accomplished is the determination of the proper working strength of long columns. The difficulty is that most of the past tests upon long columns have been made beyond the elastic limit of the material, and hence are valueless to the practical designer.

The subject of working stresses per unit of area is one upon which there is no close agreement among engineers. It is, however, one of the most important within the province of structural engineering. Some valuable results have been obtained by German experimenters upon the effects of impact and reversal of stress. Further experiments should be made in this direction and within limits which conform more nearly to actual conditions.

The strength of riveted joints and a study of secondary stresses induced in such joints and in the members connected will bear further investigation.

This very partial list will serve to indicate how fundamental are some of the problems which still require more satisfactory solution.

Passing from steel to other materials, the field for the investigator is almost untrodden. The extended use of hydraulic cement and the necessity of avoiding the use of a spurious or inferior article in important work have made the cement laboratory necessary. The fact that a well-equipped laboratory of this nature may be had at a cost of a few hundred dollars has also largely encouraged its rapid multiplication among private engineering firms. The result of placing the cement laboratory at the command of a large number of individuals is to induce a more careful and widespread study of the properties of cement, to raise the standard of specifications and to force the manufacturers to produce a superior article.

Steel and cement in combination are now abundantly used for floors of buildings and bridges, for certain classes of masonry

arches, and in foundations of steel buildings. The elastic properties of this combination have received little or no attention.

Cast steel has already proven its vast superiority over cast iron, and in many cases may profitably supplant rolled steel. More familiarity with its properties and an improvement in its mode of manufacture, which will lessen its cost, will widen its field of usefulness immeasurably.

No material has been more popular or more universally useful to the engineer than timber. Yet it has only been within recent years that a scientific study of this material has been attempted. At the present time the government is conducting an elaborate series of tests which will furnish valuable information to the engineering profession.

The proper equipment of a structural laboratory is a problem which must largely depend for its solution upon local conditions, such as the individuality of him who will most habitually direct its operations, upon the number of students, and upon the funds at hand. The apparatus should be the best obtainable. It should be large enough to produce genuine results, for nothing is more disheartening to a student than to feel that his work is not real.

While the individual proclivities of the experimenter will largely determine the choice of apparatus, there are certain fundamental pieces which form the basis of every laboratory. For example, each laboratory should contain a tension and compression machine of sufficient capacity to take the largest pieces that the engineer will have occasion to test. A machine of one hundred thousand to two hundred thousand pounds capacity, with extensions, will take full size columns and beams and is sufficiently large for most purposes. A smaller machine, of about fifty thousand pounds capacity, will be found convenient for the bulk of small tests. Several pieces of minor apparatus are needed to make the service of the larger machines most efficient. A complete outfit for cement testing is now considered indispensable in a structural laboratory. In addition, the experimenter will desire to add other pieces of apparatus to his equipment, the choice depending largely upon the nature of his work.

The college has a two-fold duty to perform. The first is one which should never for a moment be forgotten—the training of its own students for future usefulness in their chosen profession. In truly performing the first task the second is partially accom-

plished the raising of the standard of engineering education. But no less essential is it that the college should aim, from time to time, to impart directly to the engineering profession such new truths as may be of value to the practical interests of the profession. And this is best accomplished by the intelligent use of the engineering laboratory.

THE NEW DAM AT MINNEAPOLIS.

H. M. F. DAHL, '98.

Below the historic falls of St. Anthony the Mississippi river rushes swiftly over its rocky bottom in a series of rapids, extending about one mile below the falls. The descent is the greatest in the upper portion and for years the argus eye of industry had jealously watched this lavish waste of energy, with a desire of obtaining control of some of that unused power. But no particular move was made to utilize this great force until within very recent years, when it was finally decided to build a dam across the river below the falls, and to transform the head obtained into electric power. The work was commenced May 15, 1895, and a general description of the structure follows.

The dam is built across the rapids about a quarter of a mile below the falls. It extends 430 feet from the west bank, nearly at right angles, and about two-thirds the distance across the river to a massive pier rising five or six feet above its crest. Here it makes an obtuse angle and runs parallel to the east bank for a distance of 575 feet to the power house, which extends the remaining 200 feet to the bank.

A retaining wall extends along the east bank 575 feet up-stream. It is thirteen feet high, three feet wide at the top and five feet at the bottom and is built of blue limestone. The head-race, between this wall and the dam, was excavated to a uniform depth of thirteen feet below the mean water level. Another retaining wall extends along the west bank for some distance above and below the point where the dam is built into the foot of the bluff. Alongside of it is a log sluice, six feet wide, whose uniformly sloping floor is faced with steel rails imbedded in concrete. A similar sluice is built at the east end of the dam alongside the power house.

The bear-traps are three folding gates, 50 feet long, one at the west end next the log sluice, the other two, side by side, near the east end, 56 feet from the power house. They work between vertical piers built at right angles to the dam. These piers are five to eight feet thick and about six feet higher than the dam.

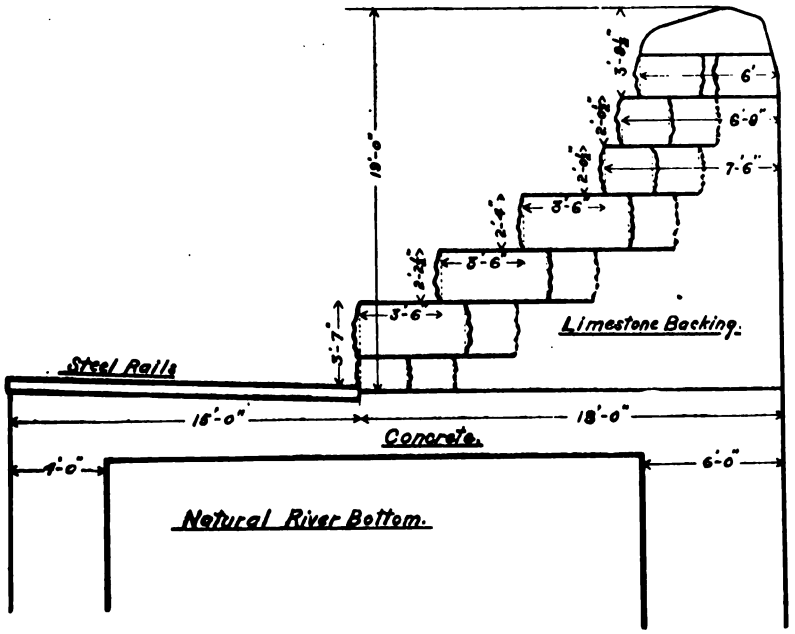
The gates are raised and lowered by hydraulic pressure controlled by two sets of valves; one set, on the up-stream side of the

dam, serves for raising the gates, the other, on the down-stream side, for lowering them. They consist of steel frames, covered with planking from three to six inches thick, and weigh about 300,000 pounds each. A four-foot girder spans each gateway, and serves for raising the gate by hand in case any portion of it should get out of order and need repairs.

Referring to the cut of its cross-section, the foundation of the dam proper is seen to consist of a layer of concrete, 33 feet wide and nearly three feet thick. Underneath this concrete are two dikes of rubble rock laid in cement; the one under the crest of the dam being about 12 feet deep and six feet thick, the other, four to five feet deep.

The dam proper is 19 feet high with a base 18 feet in width. The up-stream face is vertical. The down-stream face, consisting of St. Cloud granite, is stepped in such a manner as to change the direction of the falling water from the vertical to the horizontal with a minimum shock. Steel rails are imbedded in the concrete at the base of the dam. These rails are laid with their outer ends six inches higher than the end next to the dam; thus a pool of water is formed which acts as a cushion, and protects the con-

crete from being eroded by the sheet of water falling over the dam. The coping is a steel skeleton laid on a course of concrete. The section of the dam west of the angle is two feet four inches lower than the east portion, and is similar to it, excepting that one of the middle courses is omitted. By placing "flash" boards on its coping the water level may be raised and the head, which is normally from 16 to 19, may be increased to 21 feet. The backing of the dam is protected by rubble rock piled along the up-stream side.



—CROSS-SECTION of DAM.—
From east bear trap to angle at middle of dam. Other portion 2'-4½" lower.

The power house is built on a concrete foundation, 200 feet square and two and one-half feet thick. This also forms the floor of the tailrace, extending from the culverts to the piers of the Minneapolis and Western railway bridge, 80 feet distant. The tailrace is lined along the east side with a limestone retaining wall capped with Kettle river sandstone. Another similar wall separates it from the log sluice at the west end of the power house.

The ten tailrace culverts form the sub-structure of the power house. Their partition walls are of limestone, and the arches and skew backs of Kettle river sandstone, as is also the lower portion of the south and west walls. The latter, which separates the dynamo room from the log sluice, is five feet thick.

Since the culverts are each 20 feet wide, center to center, and there are ten 1,000 H. P. units above them, one to each culvert, it may be said that 50 horse power are developed per frontage foot, neglecting the exciters.

A short culvert, built into the bank, takes care of the tail water from the exciter turbines; it extends a little in front of the building in the form of a quarter circular bay in which the water gauge is placed.

The partition and end walls of the ten turbine chambers are of limestone. A wooden gate of heavy timbers may be lowered before the openings of the chambers and thus shut out the water of the headrace. The partition wall between the chambers and the dynamo room consists of three divisions; the middle portion of concrete—not shown in the cut—the outer portions of limestone. The circular, eight foot aperture, is lined with a riveted, steel plate cylinder, flared at the inner end to better grip the masonry. The hydraulic pressure is resisted by means of a heavy cast iron plate bolted to the cylinder. The turbo-generator shaft passes through a stuffing box in the center of this plate.

The following description of the working of the turbines will be evident by referring to the sectional view of the power house. The hollow, cast iron casing which looks like an inverted, saddle backed U, forms the central part of each twin turbine outfit. It contains inside only a horizontal cross-arm, carrying a bearing in which the shaft rotates. On either side of it are shown the guide vanes. When the gate at the entrance to the chambers is lifted, the water from the headrace fills the chamber to about seven feet above the shaft, and, rushing swiftly between the guide vanes, strikes the buckets of the turbine wheel, which the moving water drives around in passing through it into the casing, where it is deflected downward through the suction tube and into the tailrace. This suction tube is the hydraulic feature. Without it, the turbine would have to be placed in or near the tail-water to utilize the full head. The tailrace is usually a disagreeable and difficult place in which to repair a turbine. In this plant, however, the work-

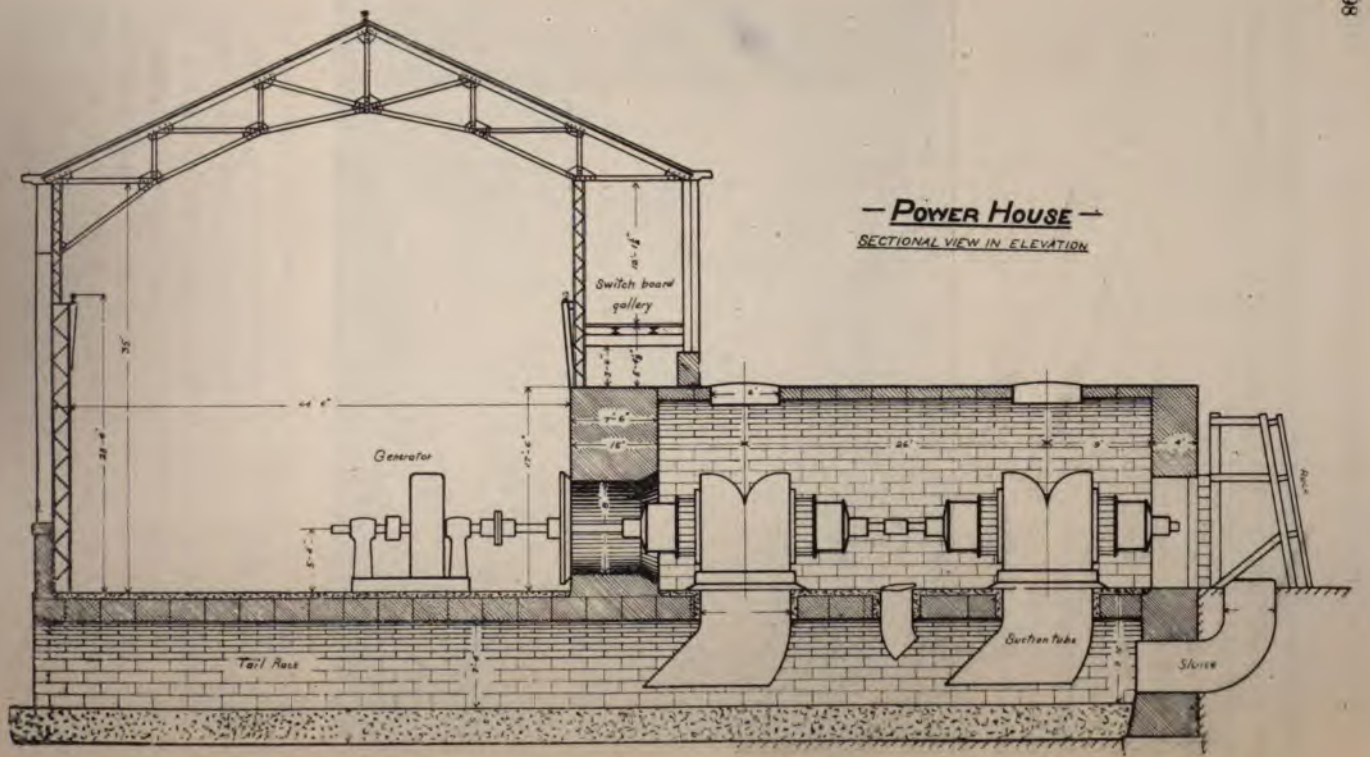
man shuts the gate of the chamber, empties it completely through the two-foot pipe in the center of the floor, and then descends through the six-foot circular opening in the roof, there being one directly above each turbine.

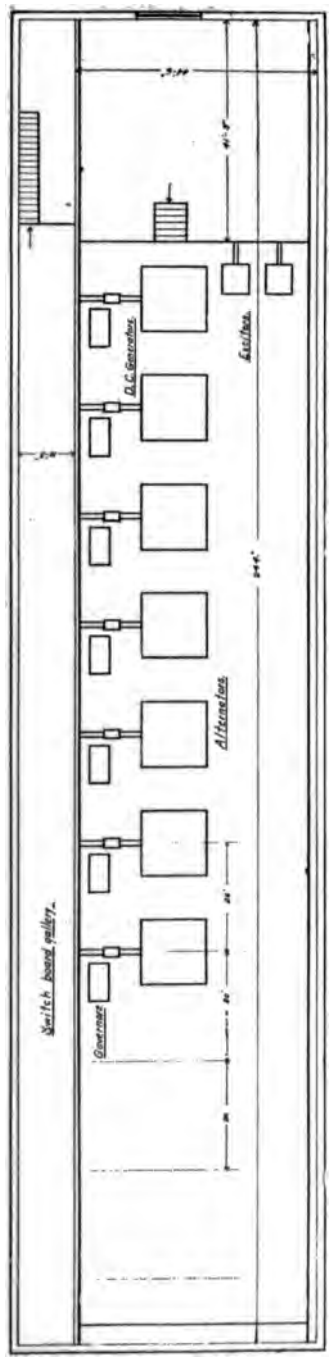
How can the suction tube utilize the full head of water? The lower edge of the suction tube is under the level of the tail-water. No air can enter and the nine or ten feet of water in the tube sustains a steady suction. Therefore the pressure on the turbines is due to the height of the water above it plus the column of water in the tube, whose sum is equal to the entire head. Two courses

of brick above Kettle river sandstone skew backs form the arch-roof of the chamber. This is covered with concrete forming the horizontal roof. A frame work of structural steel supports the rack, which extend in front of the chamber gates the whole length of the power house. The rack is a steel screen to prevent the entrance into the chambers of floating debris, which would foul the turbines. It consists of flat bars, one-fourth of an inch thick, three and one-half inches wide, and spaced one and one-third inches apart. In front of each chamber is a four-foot iron pipe

— POWER HOUSE —

SECTIONAL VIEW IN ELEVATION





PLAN OF DYNAMO ROOM

elbow making a direct connection between the headrace and tailrace. These are the waste sluices by means of which the head of water is nicely regulated, and which dispose of surplus water morning and evening.

The dynamo room is one large hall, fire and water-proof and excellently lighted. The floor, like those of the turbine chambers, is paved with concrete, on which the generators are located. The surface is dressed with two inches of asphalt. The roof is covered with Brook tile under an outer layer of slate. The walls are built of salt-glazed tile. At various points along the switch board gallery, tiles are built in the wall with their perforations horizontal furnishing eight holes for the exit of electric wires. This part of the wall is veneered inside with brick. The gallery, which is 206 feet long and ten feet wide, commands a view of every part of the room. The floor is of hard wood on three-inch pine planking. A twenty-ton traveling crane runs the entire length of the room twenty-five feet, four inches above the asphalt floor. The floor of the east end of the room is of pine, and is about four feet above the rest. Two direct connected, 100 K. W. exciters, running at 280 revolu-

tions per minute, are each driven by a pair of twenty-four inch horizontal turbines. The water driving these turbines is carried from the headrace through a six-foot underground pipe. Each 1,000 H. P. generator is also direct connected to four 250 H. P., 24 inch, horizontal cylinder-gate turbines. These run at 130 revolutions per minute.

Being a private undertaking, the work was pushed energetically from the start. The river was first deflected to the west half of its channel by a dike of loose rock and gravel faced with sheet

piling. Then the floor of the headrace, the site of the power house, and the dikes of the east section of the dam were excavated. When the stone masonry of the power house and the east section of the dam had been completed, work was commenced from the west end; dikes were thrown up and soon the massive walls were reared. The beginning of the year 1897 found the section of the dam between the pier at the angle and the west bear-trap still unbuilt, where the waters were then rushing between their narrowing confines. Would it be done before the coming of spring freshets?

According to the plans of Chief Engineer Wm. De La Barre, everything was to be completed by June, 1897. Superintendent of construction C. A. J. Morris, and his picked force of men did the work of Titans. The dike at the upper end of the now finished headrace was torn away, and the river turned into its new channel. It was barred from its former bed by a cofferdam consisting of cribs of 12x12 inch timber filled with stone and faced with sheet piling. The foundation was laid. The wall rose rapidly from the river bed, and scarcely had the last stone been laid and the coping placed, when the spring flood came.

RACE TRACKS.

HOW TO BUILD AND REPAIR THEM.

W. R. HOAG, C. E.

Having been called upon last season to take charge of the preparation of a trotting course, and finding almost no literature relative to their construction or repair, the writer offers to the profession the following, suggested by his personal experience, with the hope that it may prove helpful, in some small measure, to the profession.

A mile race course must be 5,280 feet in length, measured three feet from the pole line. The above condition, though seemingly uncalled for, appears to be the only one imposed by the racing fraternity upon track associations which desire to have their records accepted by any race association. They must be of their nominal length at that distance from the inside fence line which a horse, in a sulky, must be to safely clear the fence.

We have mile tracks with a quarter of a mile in each end curve and a quarter in each stretch; we have them on the square plan, with an eighth of a mile in each quarter turn and an eighth in each of the stretches; then the kite-shaped track has its advocates. We have tracks of various widths, from 20 to 120 feet. Some are given the amount of superelevation on the curves demanded by theoretical considerations, while others use half this amount or even less. Some are made perfectly level along the course of the track, while others allow as much as a one-foot grade to the hundred. Some will have six inches slope across the track on the straight, for drainage, and others double this amount.

This wide range touching seemingly important details would appear to argue, at first thought, the absence of proper regulation. It might seem that, where an acceptable record made on one track is to be considered as having been made on every track of the circuit and is comparable with every other similar record on any track, these tracks should be quite similar. The practical horseman, however, understands that the quantity and time of the last feed of grain or the last drink before a race, to say nothing of the previous month's training, has much more to do with shortening the record time the last second or fraction than the matters of grade, elevation at the curves or general shape of the track.

To attempt to bring these unimportant details under a rigid set of specifications would bring a large extra expense upon many associations, and thus discourage the sport without increasing the interest in it. There are well founded mechanical considerations which would indicate that a straight away mile is undoubtedly the fastest track, but the interest at the start being second only to that at the finish, as well as the matter of expense, have ruled that some form of track bringing the start and finish in front of the grand stand shall be provided. Overshadowing all these considerations affecting the time is that of elasticity of the course. While we can control this in a measure by providing a suitable foundation and carefully selected surface material, yet the amount of moisture in the track, gratuitously furnished by Jupiter Pluvius, too frequently just before or during our great races, will change our records from three to eight seconds, do what we may. So it seems that no regulation is attempted by the racing world of these things which are modified by economic considerations or governed by local conditions over which we can exercise no control. We understand that the track with semi-circular ends and an equal division of its length between the curved and straight parts has become very general and is spoken of as the "standard track," but inquiry among several associations has failed to discover any standard specifications or any knowledge of the existence of any.

Allowing that these circumstances do, to any considerable degree, affect the speed of the horse, it would undoubtedly act differently upon different horses, and thus increase the pure chance element in racing, which must increase the interest in it for all lovers of sportsmanship.

THE SELECTION OF THE SITE.

Exclusive of building, a mile track requires about fifty acres and a half mile track about fifteen acres. We assume that the association has determined upon the general locality and sum available for the purchase of land and construction of track and necessary buildings. This would, of course, determine the general shape and size, whether oval or kite-shaped, mile or half mile. At this point the services of the civil engineer should be called in, as the problems beginning with the economic selection of the site and ending when the track and buildings are fully completed are purely engineering problems. The more nearly level the ground is, the less, of course, the expense of grading.

In this the engineer can bring his special knowledge into requisition, and by taking a few readings with a level and rod can readily compare the merits of the different sites, and, perhaps, without making a formal preliminary estimate can narrow down the choice to one, or possibly to the shifting of the track in a certain piece of land whose size permits such range of choice. An eighty-acre tract and a mile track might easily bring these conditions.

That suitable surface material shall be everywhere present over the tract is scarcely to be expected and not essentially desirable. For, except the ground be unusually level, very little, if any, of the natural surface can be adopted as a "grade" for the finished track surface, and so the engineer will find it to his advantage, except perhaps a few small patches at the grade points, to work the whole track to a sub-grade, and after this has been suitably prepared the surfacing material can be added from the side, or he can obtain it from any place within or near the track with very slight additional expense.

THE BEST MATERIAL FOR THE TRACK.

As might be expected, there is a wide range of opinion as to what is the best material for the track. Since in the construction of a dozen tracks an engineer might be compelled to adopt essentially different soils for the surface materials, we will not attempt to give the exact constituents of the best sub and surface materials, but rather call attention to the conditions which these materials are desired to furnish and ask the engineer to study the different materials available in his particular case as found in adjoining roads, and determine thereby what soils or mixtures of soils will most nearly bring these desired conditions. A solid, easily drained foundation and an elastic surface are the conditions sought.

Sand or gravel will thus be very suitable sub-material, but can form only a small part of a good surface material. Its inelasticity and the ease with which it is carried from the track by the wind, alike render it unsuited for surfacing. The clays are to be avoided as far as possible, as their impervious character renders them unfit for sub-material, and in the surface material the presence of clay in considerable quantity will render the track unfit for use for some time after a rain. The fine dust into which clay readily works when dry becomes a nuisance on a track.

The sandy loams, with sufficient clay to insure a packing

when moistened, seem to meet with general favor among trackmen. The natural soils are to be preferred. The Lexington track is surfaced with natural soil. We would advise the engineer, except he has unusual opportunities of study and experience in this matter of surface material, to leave this part of the work to the judgment of some officer of the association, or, if obliged to care for these matters, let him consult freely with horsemen, whom he will find as a rule very observant of the slightest circumstance that can in any possible way affect the speed of their horses. I would recommend that such advice be followed rather than that of the expert who, with his balances and his sieves, might be able to tell the desirable constituency of the surface metal even to the number and size of the grains of sand in a given quantity of the material.

LAYING OUT THE TRACK.

Having determined the approximate location of the track, the exact determination will be made by each engineer according to his peculiar methods. One might make a topographic map of that part of the field affecting in any way such final location, while another, of a less scientific turn of mind, would make a trial location and with the profile of this seek to have the next location prove final.

The first method will be likely to result in a more economic location of the track, but might cost a day or two more work with the engineering party than the "fit and try" method.

Since the question of final location will be governed somewhat by our allowable maximum grade, we will here briefly refer to this. There seems to be no sentiment among horsemen against easy grades. Two to three feet in a quarter of a mile cannot be detected, and much more than this is permitted on first-class tracks. There should be a slight descent on the last quarter, since this not only aids the horse in getting up speed at the start, but it accelerates his speed at the finish.

The location having been fixed, by whatever methods and from whatever considerations, the staking out of the track becomes a simple problem of running two parallel tangents, 1,320 feet long and 840.34 feet apart, and connecting these by circular curves of 420.17 feet radius, or by thirteen degrees thirty-seven minutes and thirty seconds curves.

The pole line, being run out, serves the same purpose that the

center line in railroad work does from which to take "distance out" in cross-sectioning the course for determining the earthwork and setting the slope stakes.

With the grades established, the work of cross-sectioning differs in one respect only from that involved in common railroad work, and needs small comment. The roadbed, instead of being level across the track, will have a slope on the stretch of about one in sixty and on the curve one foot in twelve is much used, though this is only about half as much as demanded by theoretical considerations. The present tendency, since the introduction of the pneumatic tired sulky, is to even lessen this one in twelve superelevation. This rise should begin on the stretch about 150 feet from the beginning of the curve, ascending gradually and reaching full elevation about the same distance along the curve. The side slopes of one to one in cut, and one and one-half to one with embankment, is common.

The nature of the ground will rule, as in railroad work, as to the frequency of the cross-section stakes. For light work and common rolling ground at each hundred feet on the straight parts and at each fifty feet on curves would be sufficient for an experienced contractor's use. For purposes of determining the amount of earthwork involved, more frequent readings might be needed at certain sudden changes in the surface. All of these slope stakes will be set to the final surface as grade, then, as the work progresses, sub-grades will be set to a surface as much below final surface as it is desired to put into the surface material. Eight to ten inches makes a good depth for this and can be counted on to wear away about half an inch a year.

THE DRAINAGE OF THE TRACK.

Reference has been made to the slope of the track to secure a prompt removal of storm water from the surface of the track. It is unfortunate that this drainage must be toward and across the pole line. The necessity for superelevation at the curves makes this plan imperative. From the danger of making wash holes at the pole line at points where the storm water passes from the track to the ditch, the drains should be made about twenty-five feet apart along the track and should be very broad and shallow. A ditch about three feet inside of the pole line should be made, and of a

depth necessary to insure a certain and immediate disposal of all storm water to points well remote from the track.

THE RESURFACING OF A TRACK.

The combined action of rain washing the lighter parts into the ditches and the winds blowing away these, together with the sandy portions, gradually reduces the surface material. To meet these losses it becomes necessary to renew the surface every ten or fifteen years, depending upon the nature of the material, the amount of service on the track as well as the atmospheric conditions of rain and wind. In case the resurfacing is to be done by contract based upon volume of material on the track, sections at one hundred feet apart along the track are sufficient, but on account of the concave surface levels should be taken at each ten feet across the track at the section. By platting these on cross-sections paper the areas can be easily determined by use of the planimeter, and the work of computing very much shortened and greater accuracy insured.

The material should be put on in two layers where over six inches is to be put on, the first being leveled and thoroughly rolled before the second is added.

The foregoing is not offered as an attempt to treat all of the problems incident to the building of a race track, but it is hoped that some of the more important considerations may have received such notice as to be of service to track associations desiring to build or to an engineer called upon to assist in the construction of a race track.

COPPER MINERALS IN HEMATITE ORE.

J. H. EBY, E. M., and CHAS. P. BER KEY, M. S.

THE OCCURRENCE OF COPPER MINERALS IN HEMATITE ORE, MONTANA MINE, SOUDAN, MINNESOTA.

Reprinted from Proceedings of the Lake Superior Mining Institute.

The two parts of this paper have been prepared independently. The description of the occurrence was written for the Minnesota Iron Company's records by Mr. J. H. Eby, engineer, and is here published by permission of President D. H. Bacon.

The mineralogical examination has been carried on in the Mineralogical Laboratory of the University of Minnesota by Mr. Chales P. Berkey, and is based upon a complete series of specimens illustrating this remarkable association. Mr. Berkey has kindly consented to the publication of his results.

In reply to a letter of inquiry Prof. C. W. Hall writes:

"I think Engineer Eby has given a very clear and complete statement of the occurrence—no further points occur to me.

"The question of the genesis and chemical composition of the material found in the several ores of copper are entirely distinct questions, and should afford the subject of further study and discussion."

Prof. Thos. Egleston writes of the occurrence as follows:

"I have heard of the occurrence of native copper in this association, but I have never seen it, and I have never seen any explanation of it. The precipitation of native copper, of copper oxide and oxide of iron, is not an unfrequent occurrence in metallurgical establishments, but it is never seen in this particular condition, as in these establishments it is never subjected to any very high degree of pressure. I have several such specimens from Europe in my own collection, and I believe it is not uncommon in European mines, but I have no specific information in relation to such specimens in this country."—Secretary.

PART I.

DESCRIPTION OF THE OCCURRENCE, BY J. H. EBY.

About January, 1896, the presence of copper was indicated by the appearance of fine coatings of Malachite (Cu_2, CO_4 H_2O,

hydrous copper carbonate) upon the hard hematite ore extracted from the fourth level of the Montana Mine at a point 850 feet from the shaft. These indications of copper kept growing stronger, and a few pieces of native copper were said to have been found.

The Montana vein is a body of hard hematite, of bessemer quality, and high in iron; and is really a group of veins, the partitions between which become thinner as they extend westward, where the group apparently forms one large vein over eighty feet in width. The walls and partitions are composed of the very softest kind of soap rock and do not contain, nor do they show that they ever contained, metalliferous minerals.

The ore-body dips to the north at about 78 to 80 degrees, and pitches to the west at an angle of between 25 to 30 degrees. The veins of ore as they extend to the east pinch down to thin seams, and finally end entirely in the body of soap rock; while to the west on the second level (96 feet above the fourth, the third being dropped) it terminates against a body of jasper which forms a capping.

The specimens of copper appeared in a flat seam in the back of the breast stope of the most southern vein, fifteen feet above the floor of the fourth level, and extending west, keeping at the same height, but dipping 11 to 12 degrees towards the south. The extreme southern side of the seam was from three to ten feet north of the foot-wall, and extended 20 to 25 feet across the vein. The point where the signs of copper first appeared is about sixty feet below the jasper cap, and 265 feet below the surface of the ground. The thickness of the seam was from one-fourth to one-half inch. While no traces of malachite were to be observed above it, the ore was coated with it from three to five feet below, and often good specimens were to be found at that distance.

Until the breast had advanced eighty feet after the presence of copper was first noted the seam was filled with malachite, and not until then was there any native copper of importance found. The copper occurred in sheets one-fourth to one-half inches in thickness, and it was not entirely confined to the seam, but frequently extended through small crevices in the adjoining ore. At the point of contact with the ore the copper was altered, first to culprite (Cu_2O, red oxide of copper), then to malachite, and in some cases to azurite ($Cu_3[OH_2][CO_3]_2$ copper carbonate).

That the copper was altered to its oxide and carbonate was shown by the occurrence of an octahedron, the center of which was copper, the next layer oxide, and the outside carbonate.

Specimens of sheet copper were found as large as six by ten inches, and some were remarkably well crystallized and free from alteration products.

The seam has continued thirty feet farther than where the first important specimen occurred, and native copper is still to be found in varying quantities. One or two specimens of chalcopyrite (Cu Fe S_2, copper and iron sulphide), the size of a pea, were found, but as no importance was attached to them at the time, their position with relation to the seam was not noted.

No record can be found of any previous occurrence of copper ore in any of the workings, either on this or any other vein in the vicinity.

The accompanying sketch will show the position of the seam with relation to the foot-wall and ore-breast.

PART II.

STUDY OF THE MINERALS, BY CHARLES P. BERKEY.

In the series of specimens presented to the University of Minnesota, all phases of the associated minerals appear, with the one exception of the chalcopyrite mentioned by Mr. Eby. No specimen at hand shows this mineral. In September of the present year (1896) Mr. Eby added two specimens illustrating unusual phases of the "soap rock" enclosing the ore-body.

The specimens are grouped and entered in the catalogue of the Department of Geology and Mineralogy under the serial numbers 1591-1598 of the mineral collection, and 3901-3902 of the rock collection.

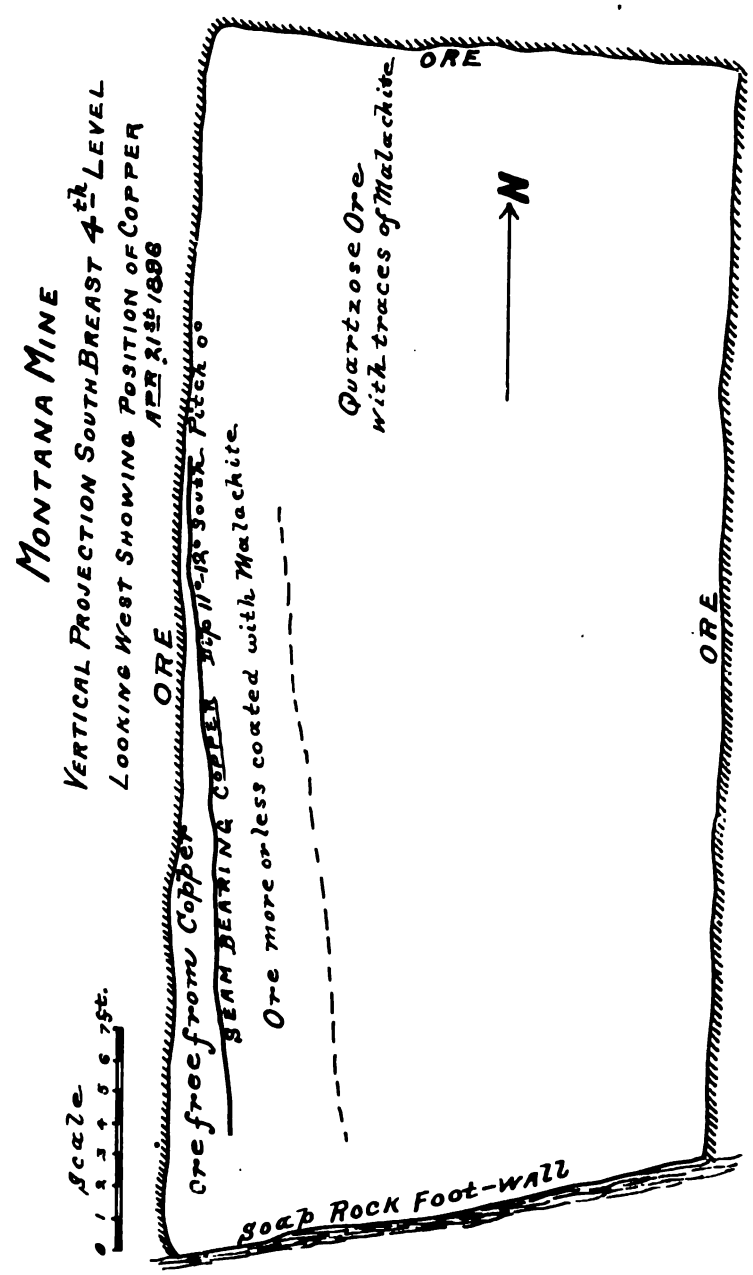
No. 1591—Chiefly hematite with copper, cuprite and malachite; one specimen.

No. 1592—Largely metallic copper, coated with cuprite and malachite; three specimens.

No. 1593—Chiefly hematite with cuprite, malachite, copper, silica and ochre; three specimens.

No. 1594—Chiefly metallic copper originally crystallized, coated with cuprite and malachite; three specimens.

No. 1595—Mostly hematite, with cuprite and malachite crystals and azurite; five specimens.


MONTANA MINE
VERTICAL PROJECTION SOUTH BREAST 4th LEVEL
LOOKING WEST SHOWING POSITION OF COPPER
ORE
Ore free from Copper
BEAM BEARING COPPER N 11°-12° West Pitch 0°
Ore more or less coated with Malachite
Quartzose Ore
with traces of Malachite
ORE
ORE
N
Soap Rock Foot-Wall
Scale
1 2 3 4 5 6 7 ft.

No. 1596—Largely cuprite with malachite, hematite and copper; ten specimens.

No. 1597—Largely hematite with copper, cuprite and malachite and ochre; one specimen.

No. 1598—Chiefly hematite with cuprite, malachite, azurite, copper and silica; five specimens.

No. 3901—"Carbonaceous shale," twelfth level cross-cut, Minnesota Mine; one specimen.

No. 3902—The "soap rock" of the mine from a horse rock, between north and south veins, fourth level, Montana shaft. The chief point of interest in the specimen is a small quantity of metallic copper which appears in the filling of a narrow vein; one specimen.

Hematite—The original mineral of the specimens, so far as the present discussion is concerned, is hematite. The fact that the various copper compounds are not scattered promiscuously through the ore, but are wholly confined to the lines of fracture in the brecciated mass and are without exception either cavity fillings or surface coatings on the hematite seems to place this conclusion beyond question. There is, however, a later development of red ochre and minute hematite crystals. This will be referred to later.

Copper—(A). In the ore-body—The metallic copper seems to be the earliest accessory mineral. It has been largely altered since the original precipitation, to the secondary products next to be mentioned; but such specimens as still bear the metallic copper present many points to support this view. Chemical tests disclose no impurity in sufficient quantity to warrant analysis, either of the metal or indeed of any of the secondary products. The native copper occurs in sheets from the seam in the ore (No. 1592), and in partially obliterated crystals coated with cuprite and malachite (No. 1594), and also in isolated threads and grains (Nos. 1591, 1593, 1596, 1597, 1598 and 3902). The evidence that copper is the primary mineral is stated below:

1. The original crystals and crystalline grains of copper remain, even with all surfaces coated by alteration products.

2. Cuprite, malachite and azurite all occur below the seam carrying the chief amount of metallic copper.

3. There is a constant occurrence of copper within an area of cuprite, with no noticeable development of porous zones. If

the metallic copper were a result of the reduction of cuprite, there would be a shrinkage in volume of 39.96 per cent. This process is always attended with the development of porous pseudomorphs. But, on the other hand, when cuprite alters to malachite, an increase in volume of 235.17 per cent results,* which is in entire accord with the bulging faces of the original crystals of copper now coated with cuprite and malachite.

4. The copper specimens freest from secondary products come from parts of the seam which were filled with sheets of copper, and show only thin coats of other minerals.

The foregoing points seem sufficient to establish metallic copper as the primary mineral of the group. None of the specimens furnish any dissenting evidence. The record of the discovery suggests no other view, unless the report of chalcopyrite, noted by Mr. Eby, can be so construed. But, on account of the apparent lack of reliable data and the total absence of any trace of this mineral in the specimens, it cannot receive serious consideration.

(B.) In the adjacent rock.—Small amounts of native copper occur quite free from alteration products in specimen 3902. It is confined, however, to the narow vein, and tests applied to other parts of the specimen do not show any trace of copper.

Cuprite—The red copper oxide, cuprite, Cu_2O, is one of the most abundant minerals present in the specimens. It is very pure; is clear red in color to very dark red; is thoroughly crystalline, and at some points is fairly well crystallized. The forms recognized are the cube, octahedron and the dodecahedron. All are small and rather imperfectly developed (No. 1592). It is always found on the specimens at hand and is a constant enclosing matrix for the metallic copper. There is no specimen of the metal without at least a thin coating of this oxide. It always forms an intermediate film between the native copper and the malachite. In many places it is quite compact and completely fills the fissures in the brecciated ore.

Malachite—The green carbonate, malachite, $Cu_2(OH)_2CO_3$, is as plentiful as the oxide. Its position is always next outside the coating of cuprite, when the two are in contact. But it extends further as a surface coating on the fragments of the ore

* Elements of Chemical and Physical Geology, Gustav Bischof, translation by Benjamin H Paul, Vol. III., p. 533.

than has been reported for any of the other minerals. There is no impurity in the better specimens. Many show fine groups of acicular prisms of very small size lining a few of the cavities. Others have the usual velvety or earthy characters (1595 and 1598).

Azurite—The blue carbonate, $Cu_2 (OH)_2 (CO_3)_2$, occurs in small amount associated directly with the malachite or hematite. A few specimens show crystallized azurite (1598). It is not at any point in direct contact with cuprite or metallic copper. Its most usual position is directly in contact with the hematite in small cavities.

Crystallized Hematite—Many areas of the ore are covered with a sparkling coat of hematite crystals, which are at least older than the malachite (Nos. 1593, 1598).

Quartz—A white and sometimes porous substance, reacting chiefly for silica, occurs sparingly as a coating and fissure filling in a few specimens. It is most closely associated with earthy hematite, and portions are colored yellow, etc., by oxide of iron (Nos. 1593, 1598).

Earthy Hematite—In a few limited areas there is a very bright red ochre. It was at first thought to be "tile ore," but examination proves it to be iron oxide (Nos. 1593, 1597).

Later than any of the minerals mentioned above is a reddish yellow, waxy film which covers some surfaces of the malachite. It is so exceedingly small in amount and so difficult to obtain in a pure state, that all attempts to determine it were unsuccessful. It contains silica, alumina, iron calcium and traces of magnesia.

PARAGENESIS.

The relationships of the different minerals may be seen by the diagram on page 111.

Origin—It is difficult to give a satisfactory explanation of the origin of this remarkable deposit. In the first place, however, it is narrowed down to a question of the origin of the metallic copper. The origin of the hematite is beyond our discussion. The oxide and two carbonates of copper are clearly secondary or derived products from the metallic copper by the action of water carrying oxygen and carbon dioxide. The cuprite developed first by simple oxidation. Malachite formed next by the addition of

water and carbonic acid, and azurite was formed last by the further action of the same process.*

Thus far the explanation seems to be borne out by the facts of occurrence. But the original source of metallic copper is not reached. It is reasonable to suppose, however, that the immediate source was a copper solution, either a sulphate, carbonate or silicate, from which the metal was deposited as a precipitate through the agency of ferrous oxide.**

This supposition seems to be so suitable in the case before us that the theories*** sometimes brought forward in explanation of the occurrence of copper will not be noted.

As to the ultimate source of the copper, data for satisfactory conclusions are not at hand. The three or four points which have any bearing on the problem are:

First—The limited amount of copper present;

Second—The local character of the occurrence;

Third—The comparatively recent development of the cupriferous minerals; and,

Fourth—The occurrence of metallic copper in the inclosing rock.

In accordance with these facts the following explanations are chosen as the most reasonable:

First—Small amounts of copper are scattered through the strata adjacent to the ore bodies, of which specimen No. 3902 is a fair example. By some change in the underground currents, this deposit was developed as a segregation. In such case, we should expect similar deposits at other points and we should detect a wider distribution in a district where so many mines are similarly situated. Specimen No. 3902 is the chief support for this explanation. But it comes from the immediate vicinity of the copper minerals, and instead of indicating a source of supply, the country rock copper may indicate the limit of penetration of the copper bearing waters.

Second—The original Keweenawan rocks were at one time more extensive than now. They doubtless have covered this very district in some period of preglacial time. They are noted for their copper producing minerals. If we assume that solutions

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* Elements of Chemical and Physical Geology, Gustav Bischof, translated by Benj. H. Paul, Vol. III., p. 509, 1854.

** Geology of Michigan, Vol. I., pt. II., pp. 43-46.

** The Copper-Bearing Rocks of Lake Superior, R. D. Irving, U. S. G. S. Monograph V. p. 425.

*** Geology of Wisconsin, Vol. I., 1873-1879, pp. 110-114.

derived from the decay of these rocks had ready access to the locality under discussion, it would form the basis of a suitable explanation.

Third—A surface erratic or local accumulation in the glacial drift would furnish conditions apparently consistent with the facts at hand. The chief objections are: The depth of the copper and cupriferous minerals below the surface, and the very recent origin of the glacial drift itself.

Of these three possible sources no one is perfectly satisfactory to the writer. Work among the iron deposits is not far advanced, and in all probability additional data will soon be forthcoming that will be of more service in this question.

So far as the writer is aware there has been no previous report of any considerable segregation of copper minerals in workable deposits of iron ores. The only analysis at hand, furnising anything definite from an American locality, is that of the Cornwall iron ore deposit in Lebanon county, Pa. In this ore there is reported* an average of about one per cent of copper oxide, melaconite, and about six-tenths of one per cent of copper pyrites.

Oxide of copper with some carbonate occurs with decomposed specular ore** near St. Clair, Franklin county, Missouri; and metallic sulphides occur sparingly in the Ozark region.***

Cuban ores also carry an appreciable amount of copper, estimated at about 0.05 per cent,* but in this case I am not sure of the mineral or chemical combination in which it occurs. Judging, however, from the amount of sulphur reported as an impurity, one would expect to find it as a pyrite. This is apparently the most common copper mineral found in iron ores.

It is not an unusual thing to encounter copper as an impurity in iron and steel, and as a furnace product in the metallurgy of iron and steel. But it is commonly in such minute quantities that no detrimental effect is produced, although two per cent of metallic copper, and usually very much less, will seriously interfere with the working of iron,** making it red short. A brief discussion of this subject does not necessarily include a treatment of

* Mineral Resources of the United States, 1883-1884, p. 270.
** Geology of Missouri, Vol. II., Report on Iron Ores, 1892, p. 95.
*** Geology of Missouri, Vol. II., Report on Iron Ores, 1895, p. 153.

* Notes on Copper in Iron and Steel, by R. W. Raymond, Trans. Am. Inst. of Mining Engineers, Colorado Meeting, 1896.
** Notes on Copper in Iron and Steel, by R. W. Raymond, Trans. Am. Inst. of Mining Engineers, Colorado Meeting, 1896.

the effect of copper as an impurity in iron, but has been referred to in order to furnish a basis for whatever is new in the discovery of copper in the Montana mine at Soudan. Even after taking account of the occurrences noted above the following points still distinguish this discovery and claim for it an addition to our knowledge of the association of these minerals:

1. A seam of metallic copper occurs in workable hematite ore,

2. In which alteration has produced the red oxide, cuprite, and the carbonates, malachite and azurite;

3. This within a limited zone in a mine not showing any other like development, and,

4. In one of the greatest iron districts of the world where nc other mine has yet shown a similar occurence.

THE NEW DISTRIBUTING RESERVOIR FOR THE WATER SUPPLY SYSTEM OF MINNEAPOLIS.

C. H. KENDALL, C. E.

For thirty years Minneapolis has been supplied with water pumped from the Mississippi river directly into the mains. During this period the population has increased from a few thousand to one hundred and ninety-five thousand, and the annual consumption of water has increased to over six and one-half billion gallons —a little more than eighteen million gallons daily average. This rapid growth of the city and the proportional increased demand for water, both for consumption and fire protection, has necessitated various changes and improvements, at frequent intervals, in its system of water supply. These have terminated in the present extensive improvement by which the supply is changed from a direct pumping system, using objectionable, unfiltered river water, to that of gravity distribution of filtered water from an extensive storage reservoir, into which the water is pumped from the river.

All previous improvements have been in the way of enlarging the pumping capacity, changing the location of intake pipes, and extending the system, but nothing has been done toward improving the quality of the supply, which for several years has been very unsatisfactory. The river is not only subject to contamination from the city sewerage and from the cities and towns above, but the water also contains an excessive amount of organic matter of vegetable origin, principally from the millions of logs floated in it yearly, polluting it at times to such an extent as to render it even dangerous.

From records, extending back twenty years, of careful examinations and analyses of the water by such competent men as Professors Peckham, Hewitt, Dodge, Leeds, Drew, Sidener, and E. G. Smith, we find them all concurring in the opinion that the supply is suspicious and not of proper purity for public use. Prof. Drew says: "That with water so heavily charged with vegetable matter, and perhaps more or less animal waste, as well as the discharge from the sewers of Anoka and the towns above us, there is continually a possibility of the development of an epidemic of disease as a result of contamination of the impure water with the germs of disease." Prof. Smith, of Beloit, in reporting analysis

made for the city in July '94, says: "I can hardly see how, in their present condition, the waters can be considered healthful and desirable, and it seems to me that if it be necessary to use the river as a source of public supply, you should make every effort to determine whether its quality can be improved by some system of storage or rapid treatment."

With the consideration of purity as paramount, Mr. Cappelen, as city engineer, has given his attention to the problem, and in the new system, has sought to give the city an abundant supply of unquestionable quality.

After investigating the different possible sources and systems of supply suggested, and after studying the supply of other cities by personal examination, Mr. Cappelen, is his report to the city council, recommended the continued use of the river supply and the construction of a one hundred million gallon distributing reservoir, with a thirty-five million gallon filter plant. And provision to be made for another reservoir of the same size for future use when it became necessary.

From surveys made, a site, admirably adapted for such an improvement, was found just outside the city limits, located between Forty-fifth and Forty-eighth avenues northeast. The land belonged to Mr. Lowry, and he generously gave the city a tract of forty-five acres—sufficient for the two reservoirs—and also in addition about twelve acres for a hundred-foot boulevard across his land from the city limits to the reservoir.

The total estimated cost of the improvement was, in round numbers, $1,150,000, and was adopted by the council in November, 1894. Work was commenced the following May. The general design of the reservoir and its operation is best obtained from the following description, given by Mr. Cappelen in his paper before the American Water Works Association in August, 1894.

"The entire land required, including that for another reservoir in the future, is bounded by Forty-fifth and Forty-eighth avenues and 'B' and 'E' streets northeast. The south end of the reservoir is located about 150 feet from Forty-fifth avenue and runs up to Forty-eighth avenue, leaving a driveway of twenty feet all around at the bottom slope. The reservoir is divided into two chambers to facilitate cleaning when necessary. The dimensions of each chamber are:

"Inside top length, 877.5 feet; inside top width, 413.5 feet;

maximum depth of water, 20 feet; the top of the embankment being 3 feet higher, or at an elevation of 317 feet above city datum. The highest part of the bottom is at an elevation of 294 feet above city datum. The capacity of each chamber is 46,500,000 gallons.

"The south chamber is partly in excavation, the north chamber is formed entirely by embankments. The design of the reservoir contemplates earthen embankments with outside slopes 1½ to 1, and inside 2 to 1. The inside slopes are first covered with two feet of puddle, then eighteen inches of crushed rock, and then to within 10 feet of the coping with six inches of Portland concrete, put down in squares of about fifty feet each, the joints being filled with a composition of tar and lime. The upper parts of the slopes are covered with Kettle River stone, 14 inches thick, not less than 10 inches in width and not less than two feet in length. The top is surmounted on the water side with a four-foot coping, one foot thick, and the entire basin enclosed by a handsome railing. The bottom of the chamber will be puddled with two feet of puddle, and then covered with six inches of concrete blocks, as on the slopes. In all embankments, a puddle wall will be constructed through the center to such a depth as may be required.

"The top of the embankments will be 20 feet wide and can be utilized as driveways. The outside slope will be sodded. In the southeast corner of the land, at the top of the reservoir, which at that point is entirely incut, the filter plant will be located. This building will be of brick, with stone trimmings, about 275 feet long and 84 feet wide, with iron trusses and roof, ceiled up on the inside with oiled ceiling. In this building the 42-inch delivery and discharge mains will be located above the concrete floor, between the filtering tanks; these tanks will be open, so that the operation of filtration will be in clear sight. This building will also contain a couple of small pumps and boilers for washing filters. Also electric light plant, all duplicate.

"The water will leave the filters through a 42-inch main running along the north side of the reservoir. From this main two 36-inch mains will run below the embankments, one to each chamber, and enter into an ornamental gate tower located on the inside of the embankment. In this tower the water will be controlled by a series of gates so that the water can be made to empty into the reservoir either at the bottom, middle, or top, as conditions may make it advisable. This tower is called the 'inlet tower.' The

outlet will be opposite in another tower, and the water can there enter, as at the inlet, at various heights.*

"The bottom of the reservoir slopes from inlet to outlet tower, two feet, and correspondingly from all sides, so that the chamber can be cleaned and flushed, and the dirty water be drawn off at the outlet tower through a drain pipe put in the same trench as the outlet pipe which delivers the water to the city main. The outlet pipes are 36-inch, running into a 42-inch pipe, which is located on 'B' street. From here the pipe runs to the river, where it is, by means of a submerged pipe, connected with the 36-inch and 30-inch mains, now leading from the North Side station to the city. The supply pipe to the reservoir will run from the North Side station by a submerged pipe and take the same route as the main from the reservoir, and also be 42 inches in diameter. At the intersection of Forty-fifth avenue northeast, the two mains will be provided with a gate each, so as to shut the reservoir off entirely, and the two mains will be connected up so that delivery can be made directly into the main going to the city."

The following is the estimated cost:

Reservoir	$327,000
Reservoir pipe lines	60,000
Main pipe lines	260,000
Drain pipe lines	40,000
Submerged pipes	49,000
Filter plant	260,000
New pumps and boilers	150,000
Total	$1,146,000

In order that the enterprise might directly benefit the unemployed of the city, the following special requirements were incorporated in the specifications:

"1st. That no laborer shall be paid less than fifteen cents per hour.

2d. That team and teamster be paid not less than thirty cents per hour, all teams to be owned by Minneapolis citizens.

3. That no men be employed except bona fide residents of the city of Minneapolis for at least one year immediately preceding

*As constructed, this has been slightly changed from the proposed plans. The towers being placed on top of the embankments, outside of the basins into which the water enters through a single pipe.

such employment, and that the men so employed shall also be heads of families, or have families depending upon them for support."

Work was successfully carried on from May to November during '95 and '96, and the amounts paid for labor during the two years was $116,735.45 and $84,724.72 respectively. The highest number of men employed in '95 was 550, and 150 teams. The highest number in '96 was 390 men and 86 teams.

A synopsis of all the work done in '95-'96, together with the financial statement, shows:

Main boulevard, from city limits to reservoir, completed. Cost	$ 20,515.81
Construction of reservoir proper, complete except as noted below. Cost	372,512.66
Total expenditures	$393,028.47

There still remain to complete the work:

Remaining coping and sheathing on the north basin, reservoir boulevards, railing, some pipe lines and sundries, estimated at	$ 49,300.00
To build pipe lines, steel	315,957.00
To change old pump	3,500.00
To electric pumping machinery	133,500.00
Suction work, etc., at pump house	5,000.00
Filter plant estimated at	250,000.00
Making a total cost of	$1,150,285.47

If cast iron pipes are used the cost would be about $27,000 more. No decisive action has been taken regarding the filter plant, but undoubtedly some form of mechanical filter using coagulents will be adopted, built on the gravity principle, from whence the filtered water will run directly into the storage reservoir. There are filter companies which guarantee to furnish water according to the following standard:

First. All odor, color, and impurities in suspension shall be removed.

Second. The free ammonia shall not exceed 0.05 parts in one million.

Third. The albuminoid ammonia shall not exceed 0.1 parts per million.

Fourth. No measurable amount of coagulant or other purifying agent used shall be left in the filtered water.

Fifth. The microbes in the filtered water shall not exceed 100 colonies per cubic centimeter.

For the material for this article, the writer is greatly indebted to papers and reports by the city engineer, Mr. Cappelen.

A CONVENIENT AMMETER PLUGBOARD.

GEO. D. SHEPARDSON, M. E.

Station ammeters like those of the Weston Electrical Instrument Company, which measure current by the fall of potential method, may be arranged without difficulty to serve a variety of purposes. These well known instruments are essentially d'Arsonal galvanometers. When designed for use as a voltmeter, the movable coil is wound with a number of turns of fine wire and is connected in series with an auxiliary coil of high resistance, the fall of potential through the movable coil being but a small fraction of the total voltage between the terminals of the instrument. When designed for use as an ammeter, the movable coil is wound with fewer turns of larger wire so as to have low resistance, and is connected in parallel with a "shunt" of much lower resistance. The current through the galvanometer coil, and consequently the deflection of the pointer, is therefore directly proportional to the fall of potential through the shunt. Since fall of potential equals the product of current by resistance, a given current may be sent through the galvanometer coil and a given scale reading obtained while the current through the shunt may have one of several different values, if the various steps in the resistance of the shunt increase proportionally as the main current decreases. The same galvanometer coil may therefore be used for measuring various ranges of current by taking suitable shunts for the galvanometer, or, in other words, by shunting the galvanometer around suitable shunts.

The determination of the resistance to be taken for a shunt to measure a desired range of current is a simple matter. Since the shunt and galvanometer are connected in multiple, the fall of potential in each circuit is the same when a given current is passing. We may write therefore,

$$e = rc = RC,$$

in which e is the fall of potential through each circuit, r is the resistance of the galvanometer circuit including coil and connecting wires, c is the current through the galvanometer, R is the resistance of the shunt and c is the current through the shunt.

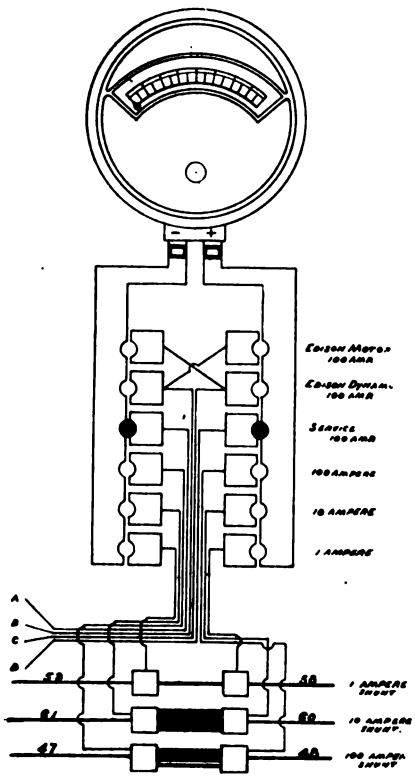
We have then as the desired resistance for the shunt,

$$R = \frac{rc}{C}.$$

If the current through the galvanometer is very small compared to that in the shunt, the latter may be considered as sensibly equal to the current in the main line, and we may write without serious error,

$$C = c\frac{r}{R},$$

or the current in the main line equals the current in the galvano-



meter multiplied by the ratio of the two resistances. When the galvanometer requires a sensible current for a full scale deflection, the range may be multiplied by a series of shunts like those used with certain forms of Siemens torsion galvanometer. If a certain

current passing through the galvanometer gives a full scale deflection, ten times as much current is required in the main line when the galvanometer is shunted by a resistance one ninth that of the galvanometer. Likewise for measuring one hundred times the current, the shunt should have one ninety-ninth the resistance of the galvanometer.

For multiplying the usefulness of a Weston round pattern ammeter, a series of shunts was arranged as indicated in the line cut. Two brass bars were arranged for fastening directly to the terminals of the galvanometer without introducing appreciable resistance. A series of smaller blocks were arranged in pairs so that by the use of tapered plugs any pair may be connected with the galvanometer bars. To one pair of blocks were screwed the galvanometer wires leading to the special alloy shunt sent with the instrument. By heavy wires leading to terminals 47 and 48 on the switchboard, this shunt may be connected in series with any desired circuit for measuring current of one hundred amperes or less.

A second pair of blocks forms terminals for other wires, A and D, which are attached to two points a few feet apart on one of the service wires supplying the laboratory with electric power from the Mechanic Arts Building. By taking a suitable length of main conductor and known length and size of lead wires to the galvanometer plugboard, calculated as above indicated, the ammeter reads directly to one hundred amperes.

The third and fourth pairs of blocks form terminals for a third pair of wires, B and C, which are connected to suitable points on the leads of the Edison dynamo in the laboratory referred to in another paper in this volume. Since the machine operates sometimes as a dynamo and sometimes as a motor, the direction of current in the leads changes. It is therefore necessary to have a means of reversing the current through the galvanometer. This is secured by having two pairs of blocks which are cross-connected as shown in the cut.

With each of the three shunts above noted, the galvanometer needle indicates one hundred amperes for full scale deflection. It was desired also to arrange the instrument for other ranges, and shunts of German silver wire were arranged so that by plugging the galvanometer around one, a full scale deflection means ten amperes. Still another shunt of higher resistance makes one

ampere give a full scale deflection. Suitable conductors connect these shunts with terminals 58, 59, 60 and 61 at the switchboard so that either shunt may be plugged into any desired circuit.

Since the galvanometer gives a full scale deflection with considerably less than one-tenth ampere, another shunt might easily be arranged so that the instrument would read milliamperes. Furthermore, since a difference of potential of only about three one-hundredths volt gives a full deflection, a small resistance connected in series would convert the galvanometer into a convenient millivolt-meter.

The instrument as outlined in the cut has been in constant use for two years and has given great satisfaction, being reliable within less than one per cent.

THE SCIENCE OF PHOTOGRAPHY.

H. C. HAMILTON, '97.

Until recently photographic work has been regarded as very closely allied to the "black arts," but with the introduction of so much prepared material for manipulation the secrets of the art are no longer confined to the few.

The processes involved in making photographs are so few and so simple that it is surprising how many people are entirely ignorant of them. Even a great many of the camera fiends who snap us unaware are ones who "push the button," leaving "the rest" for someone else to do.

Everyone at some time of his life would find a practical knowledge of the art to be a means of both pleasure and profit. Scientists have increased facilities for study and for imparting their learning to others; professional men in all departments have found it a valuable aid in their work. Its application to astronomy, its use in surgery since the discovery of the Roentgen rays, by the draughtsman to reproduce drawings and designs, by surveyors to reduce their plots to convenient size, prove its value.

The photographic lens is an eye capable of seeing much that we cannot. In astronomical work a photograph of a star group has revealed, in some cases, the presence of stars too small to be seen by the eye. The lens resembles the eye in that nothing in its direct line of sight is clear and distinct except objects lying at nearly the same distance as the point for which it is focused; while it differs in that any object at the same distance from the lens as the principal one and lying within the field, forms a distinct image. So that a photograph of some object of interest will usually contain additional objects, which often mar the effect.

There is a great variety of lenses, but all may be grouped under three heads: the single lens, the double combination, and the wide angle lens. The single achromatic lens—that having only one combination—is the best yet introduced for landscape work. This lens is plano-convex or concavo-convex, the convex side being turned toward the image formed. It is provided with a diaphragm or stop, which allows only those rays to enter which can come to a focus at approximately the same distance from the lens. This diaphragm is used also to correct spherical

aberration.. Rays of light from an object, falling on different parts of a lens, are differently refracted, and therefore do not come to the same focus. If all the rays were to come through a part of the lens so small as to have practically the same radius of curvature, they would be equally refracted and have a common focus.

The achromatic feature of the lens is to correct for color. Just as a ray of light in passing through a prism is decomposed into its constituent colors, so it is in passing through a lens. Besides having the image colored, the greater refraction of violet rays over those of the red places the actinic image—that which affects the sensitive plate—and the visual image some distance apart. This is overcome by having a combination of two lenses, one of dense flint glass and one of crown glass, so cut that they fit into each other. They have different refractive indices, the effect being to recombine the dispersed colors into white light.

For portrait work a lens is required which does not distort the image and which will represent straight or curved lines in their true character. This can be accomplished only by having two combinations, which will make every ray emerge after transmission in a direction parallel to that at which it entered. Its spherical aberration is corrected in manufacture, so that the image is sharply defined and at the same time it can be used with a large aperture. This allows an exposure to be made with very short time, on account of the amount of light admitted.

For this work the field is small and the aperture large, while for architectural and interior views the field is large and the aperture small. These lenses are very convex, almost spherical, allowing light from a wide angle to come to a focus at a short distance from the lens. Hence the name "wide angle."

In some of the cheaper forms of hand cameras there is no such thing as focusing; the lens is so constructed that rays of light from objects over eight feet distant are refracted the same as parallel rays, that is, their focus is at the same distance from the lens. But this is at the expense of distinctness and of the relative proportion of objects photographed.

There is a difference of opinion as to the change effected by the action of light, whether it is chemical—the silver bromide being partly reduced—or physical, the molecule being dissociated. Whatever it is, microscopic examination fails to show;

only the action of chemical agents make it apparent that a change has taken place.

Mercury vapors are attracted to those places in the film where an image has been received. Reducing agents, that is, compounds that easily take up oxygen, act only on those affected parts. There are two reasons for believing it to be a physical change. An exposed plate that has not been developed shows no signs of the image when the soluble silver salts are dissolved in the fixing bath. An exposed plate may have the latent image entirely removed by the action of vapors of acetic acid and the plate be as good as ever. However, it seems scarcely possible that the change is not chemical. It is probable that further research will show that a combination has taken place between the organic film and the bromine, leaving the silver salt partly reduced.

The sensitive medium in which the image is received may be on glass, celluloid or waxed paper, anything that is at the same time tough or firm and transparent.

In the earlier days the film was of collodion, made sensitive by being placed in a solution of silver nitrate.

Collodion is a solution of nitrate of cellulose—pyroxylene—commonly called gun cotton, in a mixture of alcohol and ether; to this is added iodide of cadmium or ammonium and bromide of cadmium, the combined effect being considered better than either alone. When this solution is poured on the plate, the volatile liquid evaporates, leaving a tough film. The plate is then put into a bath of silver nitrate to be sensitized. The silver combines with the iodine and bromin in the film, forming compounds sensitive to light; so this process must take place in a dark room.

In developing a negative the reducing agent acts on the silver iodide that has been affected, reducing it to metallic silver, and at the same time depositing silver from the excess of silver nitrate on the plate.

When the image is formed in all its details and with sufficient intensity, the unchanged silver iodide is dissolved with potassium cyanide or sodium hyposulphite, leaving the image formed of metallic silver in a very finely divided state, giving it a black appearance.

This process is the wet plate or collodion process and is no longer in use, except for tintypes and in reproductions for engravings.

Modern methods depend on the use of dry plates, using a film of gelatine instead of collodion, and being prepared for wholesale by large manufacturers. Their advantage lies in their convenience, their keeping indefinitely, and the greater sensitiveness and density of the film.

Gelatine is liquified in a small amount of water containing ammonium bromide, and is then well mixed with a solution of silver nitrate. The mixture is heated on a water bath at 100°C for three-quarters of an hour, and then cooled to 38° and more gelatine in liquid form is added. By varying the time of cooking, or by heating at a lower temperature for a longer time, different degrees of sensitiveness can be obtained.

In the development of dry plates, since there is no free silver nitrate present, from which silver can be deposited, the gradual increase of density of the image is due to the gradual reduction of the silver bromide deeper in the film, so that one can judge of the density of the silver image by noting when the reduction has penetrated the film and the outline can be seen through the glass on the back.

The salts of silver vary much in their sensitiveness to light. Silver nitrate is not sensitive except when combined with organic substances, and in that form it changes rapidly. Silver chloride is the least sensitive of the haloid salts, but undergoes the greatest visible change. Silver iodide is ten times and silver bromide sixty times as sensitive as the chloride but they change little in the light. The amount of change in the molecular condition of the sensitive silver salts does not seem to be directly proportional to the length of exposure, nor to the intensity of the light; but a definite amount of light is necessary to form the latent image. Too long an exposure is often as slow in development as one too short, but the usual result of an over exposure is a negative without that contrast between lights and shadows which gives life to a picture.

The negative differs from the finished picture in that when viewed by transmitted light the blackest parts represent the strongest lights in the objects photographed, while the finished picture or positive is reversed showing the lights and shadows naturally. With the exception of tintypes, daugerreotypes, and pictures of that class, all positives are made by the action of light passing through a negative. Where the light passes through the

lightest parts the greatest effect is produced in the sensitive film of the positive, forming the shadows, and where less light acts through denser parts of the negative less change is produced and the paper is left only slightly tinted.

Printing paper for positives must be of good quality to resist the rough treatment it gets. Rives paper, made in France, is that most used. It is usually sized with a coating of starch or gelatine to prevent the sensitizing solutions from sinking into the paper. It is then salted by floating on a solution of sodium chloride containing liquid albumen with some organic salts; as, the citrate and tartrate of soda. After this it is floated on a solution of silver nitrate, by which process there are left in the film several sensitive silver compounds. The different silver compounds are of use to give to the paper different colors while printing. The gelatine and albumen compounds give a red color, the citrate a purple, and the chloride a violet blue. The chloride increases the sensitiveness, while the metallic silver, that gives intensity to the print, all comes from the excess of free silver nitrate. When printed dark enough, all the silver not changed to the metallic form is dissolved by putting the printed pictures into a solution of hyposulphite of sodium. This leaves an image, formed almost entirely of metallic silver.

When an image has been printed and is put into the fixing bath, as just described, the thin layer of silver has a red color which is anything but agreeable. This would, in time, become black from the formation of silver sulphide, the sulphur being taken from the hyposulphite; but the action is too slow and the results not satisfactory.

Instead of trying to obtain a good color with silver alone, gold is used, and by this means more agreeable tones are produced. A solution of gold chloride is used; its action seems to be to give up the chlorine to the silver forming silver chloride and precipitating free gold in a very finely divided state. The thin films of gold take various colors, but with a tendency toward the blue. The toning may be carried so far that blue is the only color left; but it is usual to stop the process while there is still some of the red silver film left in the shadows, which gives somewhat of a flesh color to the picture. The changing of most of the silver to silver chloride and the removal of this by action of the fixing both bleaches the print to a very great extent.

Bleaching may be partly prevented by making the toning bath alkaline with sodium carbonate, which forms an oxide or oxy-chloride of the gold. This compound decomposes precipitating gold on the silver image while the effect of the chlorine on the silver is neutralized.

The use of albumen in the film is to give brilliancy to the picture by imparting a glossy surface. This in time loses its lustre and spoils the effect of the pictures.

There is a paper coming into general use which is not glazed and on which the image appears only in black and white when finished. The effect is obtained by means of platinum. The sensitizing solution contains both silver and platinum in the form of chlorides and silver nitrate; only the silver is affected in printing and the image appears the same as on plain paper.

It is toned a very little in gold to clear the high lights and the process completed in a solution of potassium chloro-platinite. From this solution metallic platinum entirely replaces the silver image, and the result is a picture in black and white and in the most permanent form of finely divided platinum black.

Carbon printing is an interesting method of reproduction. The sensitive medium is gelatine and potassium bi-chromate. The action of light is to liberate oxygen from the bi-chromate, and this unites with the gelatine, forming a compound insoluble in water in proportion to the intensity of the light. The gelatine may be given any color, but lamp black is mostly used, and from this the method obtained its name.

On account of the short exposure necessary for the bromide of silver, it is sometimes used for positive printing, principally enlarging. The rays of light pass through a lens and the negative and are focused on the paper, which must be so placed that no other light acts on it. It is exposed and developed just like a negative. This method is used to make the outline for the cheaper grades of crayon portraits.

The principles of photography are made use of in almost all forms of reproduction of pictures.

Even since the discovery by Daguerre, attempts have been made to reproduce objects in their natural colors. One of the methods successfully tried is that discovered by Lippman, a prominent French physicist. He reasoned that, since color can be obtained by interference of light waves, strata of silver could

be formed in the negative film so as to give color, and that these strata could be formed if a suitable reflecting surface were placed behind the plate.

When a ray of light meets a reflecting surface and is sent back on itself, the waves with vibration frequencies giving the different colors will meet incoming waves of the same amplitude of vibration in the opposite phase. This forms nodes or points of no light, and, therefore, no action in the sensitive film, and corresponding points having the double effect. Then when the fixing bath removes the unchanged silver bromide there are left particles of silver alternating with transparent film. These strata cause interference in transmitted light, taking out some colors and consequently showing a colored image. The film must be about one-tenth millimeter thick in order to be transparent, and the exposure made three minutes long. The reflecting surface behind the glass is pure mercury.

Another method of making colored prints based on photographic methods is that used in photo-lithography and similar processes. Colored printing inks are applied to surfaces which are in relief only where a certain color is wanted. These surfaces in relief are prepared from negatives on an asphalt or bi-chromated gelatine film covering lithographic stone, zinc or copper. The action of light makes the film insoluble while the parts not affected are dissolved in water, leaving the exposed surface to be etched by some corroding agent. The protected parts are sufficiently in relief so that when ink is applied by a roller they alone are touched and the color can be transferred to paper by the printing press.

Negatives for this work must be clear glass in those places where a color is to come out in relief. This can be done by screening out the light of that color; green will absorb red rays, violet screens the yellow and orange the blue. Where the red and yellow rays are intended to act on the film it must be made sensitive to that kind of light by being bathed in a solution of one of the eosin group of dyes.

It is not known definitely what the nature of the combination of these dyes with the silver salts is, but it is probable that a chemical compound is formed, sensitive to an entirely different part of the spectrum.

Another method makes use of the fact that when fine lines in different colors are ruled very closely together, or silk fibres dyed in those colors are placed side by side, the result is a mixture which acts similarly to the color screen, as in the first method. Red, green and violet colors are used 300 or 400 to the inch. A negative is made through this screen and from this a transparency which will be divided into parallel lines, according to the light transmitted. Another colored screen, made like the first, must be used with this in order to excite the three primary color-sensations. When this is viewed by transmitted light the result is an image in its natural colors.

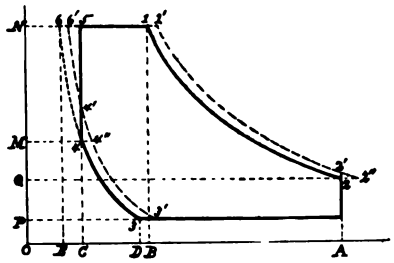
Of all these methods none is very practical excepting the second, this being used for nearly all work in colored reproductions.

THE MOST ECONOMICAL CUT-OFF FOR STEAM COMPRESSION.

DR. HENRY T. EDDY.

The result of an analytical investigation of this question was stated in the Year Book for 1895, the result being, that a given quantity of steam per stroke is used most economically in case the ratios of compression and of expansion are so adjusted to each other as to be equal.

This result is of such interest and importance that the author has thought it desirable to give, if possible, some simple and direct proof of it, instead of the rather complex analysis by which it was originally established. This seems especially desirable in order that the clearness of the demonstration may set at rest doubts that seem to have risen in the minds of some engineers as to the validity of the result. The following proof has been devised with this end in view:



Let the area, 12345, be that of an ideal indicator card, in which the curve of expansion 12, and of compression 34, are both hyperbolic, while its other bounding lines are straight and not assumed to be rounded off at the corners, as in an actual card.

Assume the steam to be admitted at a constant pressure, p_1=ON, and let the admission cease at the point B so that a volume v_1=OB is contained in the cylinder and clearance together.

Let the release occur at a pressure p_2 = OQ, and at a volume v_2 = OA, which includes both cylinder and clearance. Let v_4 = OC be the volume of the clearance, then v_2—v_4 = CA the volume swept through by the piston per stroke. Let the exhaust cease at pressure p_3 = OP, and volume v_3 = OD. The cushion steam is then compressed by the piston to pressure p_4 = OM and

volume v_4=OC, and finally it is further compressed by the steam admitted from the boiler to pressure p_1=ON and volume v_6=OE.

Then v_1-v_6=EB is the volume of the steam admitted per stroke at pressure p_1=ON. For convenience let the ratio of expansion be $v_2 \div v_1 = r_1$, and the ratio of compression $v_3 \div v_4 = r_2$. It is our object to show that for a given volume (v_1-v_6) of steam admitted per stroke, the work done per stroke with given cylinder and clearance is the greatest possible when $r_1=r_2$.

Since the curves given are hyperbolas, it is known that

Area N12Q $= p_1 v_1 \log_e r_1 = A_1$, say;

Area M43P $= p_1 v_6 \log_e r_2 = A_2$, say;

Now suppose the admission to cease at a point slightly later in the stroke, so that the corner 1 of the card is in a new position 1′, and 6 at 6′, yet these changes are to be so adjusted that the volume of steam admitted at boiler pressure shall be unchanged, then

16=1′6′ and 11′=66′, or $dv_1=dv_6=dv$, say.

By this change the work per stroke has been increased by an amount represented on the indicator card by the area 122′1′= 122″1′ ultimately; and it has been decreased by 344′3′=344″3′ ultimately.

But area N1′2″Q=$p_1 (v_1+dv_1) \log_e r_1 = A_1 + dA_1$

and area M4″3′P=$p_1 (v_6+dv_6) \log_e r_2 = A_2 + dA_2$.

$\therefore dA_1 = p_1 dv \log_e r_1$, $dA_2 = p_1 dv \log_e r_2$.

Hence in the change, the total gain per stroke is represented ultimately by

$dA_1 - dA_2 = p_1 dv (\log_e r_1 - \log_e r_2)$.

It is known from the mathematical laws of maxima and minima that this quantity must vanish in case the area of the card, and so the work done, are to be as great as possible, under the given conditions. The expression we have obtained vanishes when, and only when, $r_1=r_2$.—Q. E. D.

The particular advantage of this method of proof consists in making the algebraic difficulties as few and as small as possible.

THE GILLETTE-HERZOG COMPETITION.

In 1892 the Gillette-Herzog Manufacturing Company established the custom of offering annually, for competition by the students of the Engineering College of the University of Minnesota, a first cash prize of $50 accompanied by a gold medal, and a second cash prize of $30, accompanied by a gold medal.

The conditions of the competition for the present year are:

I. The following subjects will be admitted:

1. Mechanical engineering in such branches as machine design or processes of construction; elevators and hoists, stationary and traveling cranes; motor wagons; heating system for building or for large plant; smoke prevention; power generation, transmission or distribution; plan of manufacturing plant, including arrangement and types of machinery, to give best results in plant cost and product cost.

2. Structural (architectural) engineering, as seen in the construction of fire-proof buildings, bridges and iron and steel structures generally. Designs of fire-proof buildings should include the construction of iron and steel roofs and trusses, girders, etc.; bridge designs should give a discussion of the whole question of strains; iron and steel structures should include a comparison of the efficiency of cast iron, wrought iron and steel columns.

3. Municipal engineering, as exhibited in the problem of water supply, e. g., the design of a reservoir or pumping station, with a discussion of the attendant questions of supply and distribution of water.

4. Electrical engineering, particularly in the electric lighting of manufacturing plants and the use of electric motors in such plants.

II. While the competition is open primarily to seniors in mechanical, structural, municipal and electrical engineering, special circumstances may make it advisable to admit graduate students to the competition.

III. The names of ten (10) students selecting suitable subjects shall be presented in good faith as signifying their intention

to compete for the prizes before the Gillette-Herzog Manufacturing Company shall be bound to declare the prizes open for competition.

IV. The Gillette-Herzog Manufacturing Company and the president of the University shall name the examining board to adjudge the prizes in this competition.

V. The company assumes the right to withhold all prizes if, in the opinion of the judges the theses and designs are not of sufficient merit to deserve prizes.

VI. The judges will be expected to decide on the merits of the theses in view of their practical usefulness.

VII. Honorable mention of any theses and designs of special merit, not awarded prizes, may be made by the judges.

VIII. All theses and designs in competition shall be in the hands of the judges on or before May 25th, 1897, and shall be presented in the following manner: Each thesis, accompanied by its designs, shall be handed, without the name of the writer, or any designating mark whatever, to the Dean of the College and by him shall be delivered to one of the judges.

IX. All theses and designs shall be presented in duplicate; one copy shall become the property of the University of Minnesota and the other shall become the property of the Gillette-Herzog Manufacturing Company.

The prizes awarded under each annual offer were as follows:

1892.

First prize to Leo Goodkind for a design of a fire-proof building with steel skeleton frame.

Second prize to James H. Gill for a design of a high speed Corliss engine.

1893.

First prize to Delos C. Washburn for a design of a steel frame of a machine shop or iron foundry.

Second prize to Frank E. Reidhead for a design of a series electric motor.

1894.

First prize to Andrew O. Cunningham for a design of a steel arch bridge.

Second prize to Harriet E. Wells for a design of a wrought iron gate.

Recommended for honorable mention:

Charles H. Chalmers for a design of a 15 h. p. electric motor.

George E. Bray for a design of a steel boiler.

1895.

First prize to Leslie H. Chapman for a design of a swing bridge.

Second prize to Harry L. Tanner for a design of an induction motor and a polyphase generator.

1896.

First prize to C. Paul Jones for an original design for the steel frame of a 10-story building.

Second prize to C. Edw. Magnusson for specifications for an electric light plant for the Gillette-Herzog Mfg. Co., Minneapolis.

EDITORIAL.

The advertisements in this issue cover every branch of the engineering profession. The firms represented are among the best and most reliable in this country, and it is their patronage that enables the Year Book to be published.

A favor will be conferred on the Society by its friends and members if on writing to any of these firms they will mention that they saw their advertisement in the Year Book.

The Engineers' Society wishes to acknowledge the courtesy of an exchange with the following colleges and societies.

GENERAL EXCHANGES.

University of Michigan, "The Technic"; Purdue University, "Proceedings of the Purdue Society of Civil Engineers"; University of Tennessee, "The University Scientific Magazine."

SINGLE EXCHANGES.

University of Illinois, "The Technograph"; Bulletin of the University of Wisconsin; Transactions of the American Society of Irrigation Engineers; Rensselaer Polytechnic Institute; "The Polytechnic"; Cornell University Quarterly; Pratt Institute Monthly.

The lecture of Mr. Woodman, secretary of the C., St. P., M. & O. R. R., was especially appreciated, and is printed in full in this issue.

The Board of Editors wish to acknowledge their indebtedness to Miss Margaretta A. Stevens, of the School of Design, for the artistic cover page design of this issue.

A Suggestion.—If all lecturers before the Society would have the kindness to have their lectures written out, so that if desired they could be printed in the publication of the Society, it would greatly accommodate the Board of Editors of the Year Book.

The different methods of setting forth electrical phenomena to the student are quite often highly interesting, especially when making use of apparatus originally designed for altogether different purposes. Until the present year the electrical laboratory had been somewhat lacking in polyphase machinery, but owing to the inventive genius of Prof. Geo. D. Shepardson, this can no longer be said of it.

The T. H. arc machine and the Edison constant potential dynamo, mentioned in his articles, are now very successfully taking the place of expensive machinery, the purchase of which would otherwise have been necessitated. Although they are not so efficient as apparatus designed for that particular use, yet they are so thoroughly interchangeable that in the eyes of the student they far surpass any apparatus that could have been purchased for practically illustrating direct alternating and polyphase currents.

The exploring engineer is the pioneer in his profession. His work, preceding the tide of immigration, forms the basis of that of the geographer and geologist, and gives an invaluable aid to the naturalist. Among the graduates from our college, Mr. W. C. Weeks may well be ranked among the foremost and as having had the most varied experience in this line of engineering. To the embryo engineer who longs for adventure and imagines that the day of the explorer is past his article on engineering in South America in this issue of the Year Book will be a pleasant surprise, showing, as it does, that there are yet vast territories, even on our own continent, entirely unexplored.

LIST OF ADVERTISERS.

ASSAYERS, AND CHEMISTS' SUPPLIES.

The Denver Fire Clay Co., - - - - - - Denver, Colo.

CEMENT.

Meacham & Wright, - - - - - - - - - Chicago, Ill.

Western Cement Co., - - - - - - - - Louisville, Ky.

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October 23, 1896:
Wiring of Buildings - - - - - - - O. G. F. Markhus, '97
November 6, 1896:
Lighting System of Armory - - - - - W. L. Miller, '97
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February 6, 1897:
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April 14, 1897:
Electric Elevators - - - - - - - G. Rosenbusch, B. E. E.
May 14, 1897:
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CHARLES A. LARSON

Died March 28, 1897

WHEREAS, It has pleased God, in His infinite wisdom, to remove from our midst our esteemed friend and classmate, CHARLES A. LARSON;

RESOLVED, That we, the members of the Engineers' Society of the University of Minnesota, hereby express our sincere regret and sorrow, and extend to his bereaved family our heartfelt sympathy in their great affliction; and be it further

RESOLVED, That a copy of these resolutions be spread upon the minutes of this Society, and that a copy be sent to his parents.

ROY V. WRIGHT.
ADOLF WAGNER.
C. A. GLASS.

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IN THE

UNIVERSITY OF MINNESOTA.

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1886.

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1887.

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1888.

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Loe, Eric H.....B. M. E. Mechanical Engineer with Nordyke & Marman.
Minneapolis, Minn.
Morris, John.....B. M. E. Mechanical engineer and assistant supt. of the Plano Mfg. Co.
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Minneapolis, Minn.

1889.

Coe, Clarence S.....B. C. E. Civil Engineer in Eng. Dept. of C., M. & St. P. R'y Co.
Wenatschee, Wash.

1890.

Burt, John L.....B. C. E. Commission merchant.
Minneapolis, Minn.
Dann, Wilbur W.....B. C. E. Asst. Engineer Lake Superior Power Co.
Sault Ste. Marie, Mich.
Gilman, Fred H.....B. C. E. Associate editor Mississippi Valley Lumberman.
Minneapolis, Minn.
Greenwood, W. W.....B. C. E. Editor and publisher of "The Christian News."
Minneapolis, Minn.
Hayden, John F.....B. C. E. Editorial dept. Mississippi Valley Lumberman.
Minneapolis, Minn.
Higgins, John T.....B. C. E. Physician.
St. Paul, Minn.
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Boston, Mass.

1891.

Aslakson, Baxter M.....B. M. E. With the Stillwell-Bierce and Smith-Vaile Co.
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Buffalo, N. Y.
Douglas, Fred L.....B. C. E. Civil Engineer.
New York City.
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Huhn, George P.....B. E. E. Flour City Nat'l Bank.
Minneapolis, Minn.

1892.

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Minneapolis, Minn.

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Larson, C. A. (deceased.)
Latham, W. H.
Lee, E. A.
Leedy, J. W.
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Markhus, O. G. F.
Wilson, M. F.
Woodford, G. B.
Woodman, H. H.
Woodward, E. E.
Wright, R. V.
Wright, W. H.
Yager, Lewis.
Zeleny, F.
Zintheo, C. J.

1875.

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1876.		
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1877.		
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1884.		
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1885.		
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Hankenson, John L. Minneapolis, Minn.	B. C. E.	Asst. Engr. C. M. & St. P. Ry.
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1893.

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1894.

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Trask, Birney E. (B. C. E., '90). Highland Park, Ill.	C. E.	Professor of Mathematics and Drawing, Northwestern Military Academy.

Weeks, William Charles....B. C. E. Minneapolis, Minn.		U. S. Assistant Engineer.
	1895.	
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Chapman, Leslie H.....B. C. E. St. Paul, Minn.		Bridge Dept. G. N. R. R.
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Christianson, Peter..(B. E. M. '94). Minneapolis, Minn. E. M.		Instructor, U. of Minn.
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	1896.	
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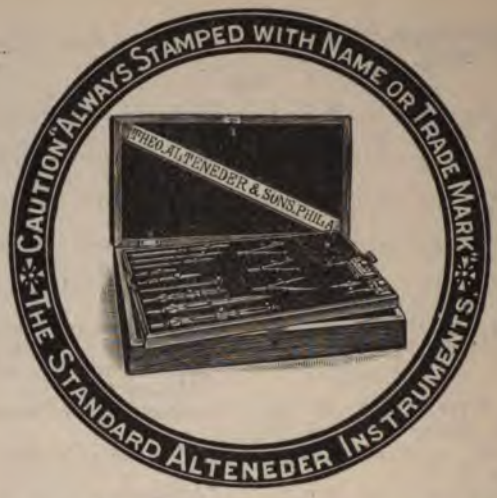

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1898.

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.....TABLE OF CONTENTS.....

Some Notes on Dynamite.....Arthur Edwin Haynes 1

Narcotine and Narceine.....G. B. Frankforter and Frank H. Keller 11

The Motion of a Base-Ball.....C. H. Hinton 18

A Few Queries.....Geo. D. Shepardson 29

Reclamation of Wet Land.....W. R. Hoag 41

Geology of the Mesabi Iron Range.....U. S. Grant 49

Shop Work for Engineering Students.....J. H. Gill 63

Bridge Erection.....Frank H. Constant 66

A High or Low Tension Alternator.....H. F. M. Dahl 76

Electric Lighting.....W. I. Gray 81

Direct Current Generators in Parallel.....Frank W. Springer 86

THE

YEAR BOOK

OF THE

SOCIETY OF ENGINEERS

MAY, 1898

SOME NOTES ON THE MECHANICAL TESTS, USES, EFFECTS AND HISTORY OF DYNAMITE.

ARTHUR EDWIN HAYNES.

INTRODUCTION.

From the heading of this paper it will be observed that I do not propose to discuss what dynamite *is*, but rather some of the things it *does*. Suffice it to say, as to its composition, therefore, that it is principally composed of nitro-glycerine, the elements of gun-powder and wood-pulp, or some other absorbent like peat or infusorial earth.

Nitro-glycerine, the principal ingredient of dynamite, was discovered in 1847, (two years after the discovery of gun-cotton) by Professor Sobrero, of Turin, Italy. It was not until 1867 that the recently deceased Alfred Nobel, a Swedish engineer, suggested its use for explosive purposes. "According to Nobel one measure of the liquid fluid (nitro-glycerine) yields on explosion 10,384 measures of gas, while one measure of gunpowder yields only 800 measures of gas."

In Europe there is now manufactured about 10,000 tons of nitro-glycerine annually, while in the United States about the same quantity is manufactured.

It is an interesting fact that nitro-glycerine has its use in medical practice. It is used by homeopathists for curing headache. The smelling of it, or the breathing of the smoke after blasts have been fired, I know from my experience underground in mines, produces a violent headache. So in accordance with their maxim, "*Similia similibus curanter*," they give it to cure headache. In the United States Dispensatory its use is recommended in the treatment of angina pectoris, asthma, convulsions, asphyxia, etc.

MECHANICAL TESTS.

I have in mind but four different methods of mechanically testing the explosive power of dynamite aside from its *actual use* which is, no doubt, the best of all tests. For convenience of description I will call these (a) the free detonation test, (b) the lead frustum, or expansion test, (c) the mortar, or projectile test, and (d) the pendulum or foot-pound test.

On the 25th of November, 1892, by invitation of the officers of the Hancock Chemical Company, I visited the works of that company, located at Woodside, Houghton Co., Mich., about three miles from the Michigan Mining School, to look over the various steps in the manufacture of dynamite and to witness their methods of mechanically testing its explosive power. The plant of this Company is quite an important one, as will be inferred from the fact that it was then furnishing 100,000 lbs per month of this explosive to three mines of the "copper country" in which it was situated; to the Calumet and Hecla mine 50,000 lbs; to the Tamarack, 30,000; and to the Osceola, 20,000. At this place I observed, from a distance of a few feet, the first two tests which I have already mentioned and, by the kindness of the officers of the company, was permitted to bring the results of these tests away with me. The engravings of which are herewith shown.

The first or (a) test consisted in placing a piece of 50% dynamite on top of a piece of strap wrought iron ⅜ of an inch in thickness and immediately over a hole in a large nut, or burr, on which the strap iron rested, all being placed on the top of a stump a few feet from the office.

The piece of dynamite was cut off from a stick, or cylinder,

about 1¼ inches in diameter and was about ¾ of an inch long; it weighed a troy ounce.

It was detonated by a short fuse, to the end of which was attached a copper cap charged with fulminate of mercury. No weight was laid on the dynamite and only a small piece of pine was laid on the fuse to keep the wind from blowing it off.

The effect of the detonation is here shown. It made a circular hole through the strap iron about 1¼ inches in diameter and so smooth that one could readily believe it to have been made with a steel punch of that size.

The second or (b) test was made by putting a charge of the same per cent of strength, weighing only 24 grains troy, into a cylindrical cavity six cubic centimetres in capacity, in a frustum of lead of size sufficient to weigh several pounds; and after sifting dry sand into the hole on top of the charge, as tamping, it was detonated with fuse and cap as in test (a). In this case the cavity was expanded 82 cubic centimeters, as was easily determined by measuring its capacity with a burette, 12 cubic

centimeters having been deducted for the expansion caused by the cap on detonation, which had been determined by previous experiments.

The effect of the detonation of this charge is seen in the engraving of the second specimen where I had sawed the lead frustum nearly through and bent the upper part back so as to show a horizontal cross section of the cavity. I have donated these specimens, also some infusorial earth, peat, and wood pulp, used in the manufacture of dynamite, to the School of Mines of this University, where they may be seen.

The third or (c) method is by means of a mortar carrying a ball which is projected from it by the detonation of a charge behind the ball.

I am informed, by recent correspondence of one who has been employed extensively in the manufacture of this explosive for many years, that *most companies* engaged in its manufacture mechanically test it by this method, using the "Epronette Mortar." In speaking of the mortar used by his company, "The Hercules Powder Company," of Cleveland, Ohio, he says, "Ours (mortar) has a 32 lb slug ball. Of course, we have to use small charges (about 60 grains), or we would burst the gun."

Tests made in this way would only show the relative pro

pelling strength of the different grades, or an imperfect comparison of different manufactures on percentages."

The fourth or (d) method is, I think, the most scientific. It consists in detonating a charge behind an iron plunger fitting into a cylinder or mortar, and thus driving it against the bob of a heavy iron pendulum and causing it to swing through an arc which is carefully measured. The foot pounds of work done is approximately the product of the weight of the pendulum and the radius times the versed sine of the angle through which it is made to swing.

USES.

The principal uses of this explosive are found in engineering (civil, mining and military); in quarrying; in foundries, for breaking up old iron; in lumbering, for breaking up "roll-ways" and log-jams; in breaking up ice-gorges; the ice in harbors and rivers and in clearing land from stumps and boulders; and last, and most lamentable, is its use by that enemy of human society, the anarchist.

It is safe to say that the use of this powerful agent has almost revolutionized some of the former methods of engineering, and its benignant power has even made the old farmer smile as he has seen the boulders, that have so long baffled his power, broken into fragments, and the stumps around which he has ploughed many a year, lifted into the air and scattered like a bag of feathers in the wind. And he has smiled again as he has learned what a mighty time-saver it is, even in his humble occupation; for with the aid of two men and this potent helper, he can blow out from 100 to 200 stumps per day.

EFFECTS.

Here permit me to quote two or three descriptions of its use and effects:—

"A blast recently fired in Graniteville, Mo., resulted in the dislodgment of 150,000 cubic feet of granite in one mass, without a fracture or seam."

"BIGGEST BLAST EVER KNOWN.

THE TREMENDOUS EXPLOSION NECESSARY IN CLEARING THE HELL GATE PASSAGE INTO NEW YORK HARBOR.

The removal of Flood Rock at Hell Gate was the occasion

of the largest blasting operation the world has ever seen. The island or rock was about nine acres in extent, and the *Brooklyn Eagle* says that to blow up this huge mass it was honeycombed under low water mark with tunnels, twenty-four galleries running in one direction, intersected by forty-six at right angles. These galleries were pierced in every direction by drill holes, of which there were 12,561, each with a depth of nine feet and a diameter of three inches, in all more than twenty miles of drill holes. Into each of those were inserted first a cartridge of rackarock (one of Sprengler's patent explosives) and second a cartridge of dynamite, the two together filling the entire bore of each drill hole. In all, there were used 240,399 pounds of rackarock and 42,331 pounds of dynamite. In the operation, 80,166 cubic yards of rock were tunneled out and 270,717 cubic yards were blasted. Water was admitted to the mine and it was exploded Oct. 10, 1885. The resistance offered to the explosives equaled 500,000 tons of rock and 200,000 tons of water. The spark which exploded this enormous mine was sent along the wires by the little fingers of the young daughter of General Newton, the chief engineer. As she pressed the button which completed the electric circuit, the spectators, whose eyes were riveted on the visible surface of the doomed rock, heard a dull rumble, accompanied by a seeming sinking of the earth, and then, so sudden that its rise was scarcely perceptible, there stood above Flood Rock a mighty column of water, nine acres in area and 200 feet high, with the pinnacles of foam and spray piercing still higher, the whole mass looking like a magnificent iceberg of crystal clearness and enormous proportions. For a second, it seemed to hang motionless in the air and then with a crash it collapsed in irregular mountainous foam, casting up acres of spray in all directions and sending a great wave splashing against the shore. A dazzling yellow cloud of gases from the explosives hung over the boiling water. The shock was plainly felt in all parts of New York and Brooklyn, but caused no damage anywhere."

Not only is it a great time saver but it is equally a money saver. One lumberman in speaking of its use said that last season he saved one thousand dollars in labor alone by the use of fifty dollars' worth of Hercules Powder, which is composed

mostly of the elements of dynamite, and is covered by a patent dated Nov. 17, 1874, granted to J. W. Willard of Cleveland, Ohio.

STRENGTH.

As to the relative strength of this Hercules Powder one can judge from the following statements:

"A quarter of an ounce of the best blasting powder, in a proof mortar, assisted by the exploding cap, will throw a thirty pound ball say seventy feet. The same quantity of Hercules No. 1 will throw the ball over *seven hundred feet*! And for breaking boulders, and for block holes in quarries, there is full this difference. One ounce exploded on a plate of cast iron, two feet square and two inches thick, will break it in pieces."

Dynamite is made of all grades of strength containing from 10% to 75% of nitro-glycerine. The quality to be used depends on the character of work to be done; for example, the grade that would do good work in one kind of rock would fail in another. The grade most used is the medium grade of 40%. The world famous Calumet and Hecla copper mine, of the Lake Superior region, after experimenting with many kinds and grades, at last decided that 50% was best suited to the rock of that mine and have used that grade exclusively for many years. The almost equally famous Tamarack mine of that region uses 55% strength. "A great advantage is that the higher grades can be used in water without other protection than the ordinary paper cartridge in which it is packed for use."

PERSONAL OBSERVATION.

My personal knowledge of its use covered a period of three years, 1890-93, in the Lake Superior copper region, where I was frequently permitted to observe the methods of using it and to study its effects in the following named mines: "The Quincy," "The Franklin," "The Osceola," "The Tamarack" and "The Tamarack Junior." It is intensely interesting to observe with what rare skill and judgment the practical miner in these mines will drill his holes for the different charges so that when they are fired the maximum quantity of rock—"ground," as it is more frequently called by the miner—is brought down. A single, well-calculated blast will bring down from 20 to 50 tons of the

copper-bearing rock of these mines. Not the least interesting and exciting part of a trip underground in these deep mines, some of which have vertical shafts of over 3,000 feet, is the noise of these heavy blasts in these rocky depths. As they follow each other in quick succession, the very earth seems to groan and stagger with pain.

THE QUANTITY USED.

The amount of this explosive used per year in this region alone is surprisingly large; it is over 1,500,000 pounds of 50% strength, more than a million pounds of this is Hercules Powder, which is mostly used in the Calumet and Hecla mine. More than 35,000,000 lbs were used in the United States in 1893.

SAFETY IN HANDLING, IN USING AND IN MANUFACTURE.

In 12 years one firm has shipped to this great mine over 10,000,000 lbs, and while this had to be handled ten or twelve times before reaching the mine, still the firm informs me that it has yet to learn of one life's being lost while this was in transit.

The Hercules Powder Company, of Cleveland, Ohio, says:

"We have transported it safely by every method known; by wagons, steamers, railroad cars and on pack animals over high mountains.

"We once had a mule, loaded with boxes of Hercules, fall from a sharp declivity on the Sierra Nevada mountains, and fall some two hundred feet. The poor mule was killed, but the Hercules was not exploded."

An authority on the subject says:

"The Calumet and Hecla Mining Co. have used some 12,000,000 lbs in their mine with scarcely an accident," and he adds: "The commonest, stupidest miner will soon learn how much dynamite to put in the hole to fire a blast and he will know with ordinary care that it is a *very, very* safe explosive."

It is a notable fact that out of over 7,500 men employed in the copper mines of Houghton Co., Mich., during 1892, less than one in one thousand was "blasted" and all but one of these cases, says the mine inspector, were traceable to carelessness.

"Four thousand miners have been using it for 16 years in one district without accident."

Miners sometimes carry sticks of frozen dynamite in the legs of their boots and in the pockets of their woolen shirts until it is thawed (it freezes at 42° F.); in fact, one of the principal companies in its advertising pamphlet says: "This method of thawing is often practiced and is a good way where small cartridges are used." I here quote from two authorities on the subject; one in a personal letter says: "The manufacture of dynamite is safe and easy, only requiring good materials and careful handling." The other adds: "During the past 17 years we have manufactured and sold over 40,000,000 lbs of powder (Hercules) and no person has been injured by it in our factory or in transportation, and but two accidents while using in mines. Of these two, one was blasted in drilling out an old charge, the other by putting a hot bolt in the water in which he was thawing it."

A terrible example, however, of the effects of carelessness in its manufacture was given several years since at the Hancock Chemical Works of which I spoke in the beginning of this article, when, without an instant's warning, the works were completely destroyed by its explosion, and of the six men only a cigar box full of their remains was found. Eternal vigilance is the price of safety in its manufacture and in its use.

Cost.

It seems strange that so much power can be bought for so slight a cost.

The company of which I have just spoken advertises Good Stump Powder at $4 per case of 50lbs, while the Hercules Powder Company of Cleveland, Ohio, furnishes the following approximate price list:

No. 4-	20% Nitro-Glycerine, 9 cts. per lb.	For slate and bank blasting, softer rock-work, limestone, sandstone, etc
No. 4-s	25% Nitro-Glycerine, 10 cts. per lb.	
No. 3-	30% Nitro-Glycerine, 12 cts. per lb.	
No. 3-s	35% Nitro-Glycerine, 13 cts. per lb.	
No. 2-	40% Nitro-Glycerine, 14 cts. per lb.	For medium hard rock-work and stump blasting
No. 2-s	45% Nitro-Glycerine, 15 cts. per lb.	
No. 2-ss	50% Nitro Glycerine, 16 cts. per lb.	For very hard rock, iron and copper ores, etc
No. 2-sss	60% Nitro-Glycerine, 19 cts. per lb.	
No. 1—	65% Nitro-Glycerine, 20 cts. per lb.	For breaking masses of iron, salamanders, hardest flint and quartz rock.
No. 1-xx	75% Nitro-Glycerine, 22 cts. per lb.	

HISTORY.

The manufacture of dynamite in the United States was begun in California in 1868, (the date of the organization of this University) by Jas. Howden and J. W. Willard, and the first that was sold was to Col. C. N. Mendall, U. S. Engineer, who used it on Lime Point, in San Francisco Harbor, in the early winter of that year.

From that small beginning its use has steadily increased so that no large job of engineering, requiring instantaeous and great force, is now undertaken without its employment.

A notable recent example of its use was in the sinking of the recently-completed Red Jacket shaft of the Calumet and Hecla mine, the greatest mining shaft in the world; it is as large in horizontal cross section as six ordinary sized shafts, and descends vertically 4,900 ft., only 380 ft. less than a mile. It was completed after nine years of incessant labor, night and day, at the enormous expense of over two and a half millions of dollars.

A CHEMICAL STUDY OF THE ALKALOIDS NARCOTINE AND NARCEINE.

G. B. FRANKFORTER AND FRANK H. KELLER.

Until recently, the alkaloids, like the albuminoids, were considered so complex that nothing definite concerning their chemical composition seemed possible. The researches of Hofman and Würtz, resulting in the isolation of a number of organic bases, the discovery of pyridine by Williams, and quinoline by Runge, laid a foundation for a systematic study of these important compounds, which, sooner than the most sanguine expected, resulted in the historical synthesis of conine*. These successful experiments naturally led to a careful and exhaustive study of the more important compounds. While most of these experiments have been directly unsuccessful, a few of the alkaloids have yielded and are now made in the laboratory. In fact, the prospects of making even the complex seem bright.

The most interesting and perhaps the most important group of these plant alkaloids is that commonly known as the "opium group," including, besides several less common ones, morphine, codeine, thebaïne, papaverine, narcotine and narceine. Of these, morphine, codeine and narceine are most important. All, however, have been carefully studied in an effort to produce morphine, the most important member, synthetically. While at the present time morphine has resisted the most determined efforts, much light has been thrown on the general structure of the whole group; and it is reasonable to predict that in the near future all of these compounds can be made in the laboratory.

In the early history of the alkaloids, they were, from their general chemical behavior, regarded as amines or derivatives of ammonia. The discovery, however, of quinoline in quinine and pyridine in conine and nicotine, soon revealed their true chemical structure.

The following experiments were begun on narcotine and

*Ladenburg—Berichte d. deutsch. Chem. Gesellschaft,—19-2578.

narceine with the hope of clearing up some of their complex reactions which demanded a closer and more exhaustive examination. Although the general structures of these two alkaloids are now known, the reactions, resulting in the change of the one into the other,* are so deep-seated that no explanation seems possible. The formation of an azoimido derivative from narcotine methyl chloride appears as utterly inconsistent with general principles, as would the synthesis of strychnine from milk sugar.

In 1888, experiments† were made with narcotine resulting in a general solution of the structural formula as well as the isolation of a number of important derivatives. Thus, by treatment with methyl iodide, a narcotine methyl iodide was formed which, by a complex process was converted into a base resembling very closely the alkaloid narceine in physical and chemical properties as well as empirical formula. The base was called pseudonarceine and the following reaction given:

$$C_{22}\,H_{23}\,NO_7 + CH_3\,I = C_{23}\,H_{26}\,NO_7\,I.$$

By treating this iodide with an alkali and allowing to stand or by passing steam into the solution, the iodine was completely removed, a rearrangement of the molecule taking place at the same time:

$$C_{23}\,H_{26}\,NO_7\,I + KOH = C_{23}\,H_{27}\,NO_8 + KI.$$

While these equations are comparatively simple, what actually takes place in the above treatment is quite the opposite. Besides the base narceine, which represents less than one quarter of the iodide used, a second substance is formed which was at first identified as dimethyltoluolazammonium silveriodide,‡

$$C_7\,H_6{\cdot}N_3\,(CH_3)_2\,I\cdot 2Ag\,I.$$

This strange reaction led to a careful examination of the above substance, resulting in a number of analyses,§ though without obtaining satisfactory results. The substance resembles the azoimido compounds of Zinke and Lawson,¶ although the results of analyses do not agree with those compounds. If this

*Annalen d. Chemie u. Pharmacie, 245-311, and Inaug. Dis. Berlin, 1893, G. B. Frankforter.

†Annalen d. Chemie u. Pharmacie, 247-167.

‡Annalen d. Chemie u. Pharmacie, 247-168.

§Thesis for M. S. degree by R. S. Shepherd.

¶Annalen d. Chemie u. Pharmacie, 240-128.

strange substance is formed, then according to the equation, only one-fourth of the narcotine can be converted into narceine. Experiments bear out this assumption. The narcotine substance was prepared under different conditions and compared with the pure azoimido compound. They were similar so far as they were insoluble in all common solvents. The Zinke and Lawson substance was soluble in aniline, nitrobenzole, quinoline and a strong solution of sodium hyposulphite from which it was obtained in well crystallized form. The substance from narcotine proved to be insoluble in cold nitrobenzole, but slightly soluble in hot, changing color from a light gray to a light lemon yellow. On cooling, the yellow color disappeared and the soluble part was immediately precipitated out as an amorphous mass. There was no indication of a double salt formed when treated with aniline. In fact, the same yellow substance was obtained from nitrobenzole, aniline and quinoline. The narcotine substance melted at 184°–186° C. The Zinke and Lawson substance at 128°–130° C. Neither substance contains water of crystallization.

Analyses of the purified narcotine substance gave the following numbers:

I. 0.1937 grams of dried substances gave 0.1279 CO_2 and 0.0316 H_2O
II. 0.2162 " " " " " 0.1413 " " 0.0345 "
III. 0.2112 " " " " " 0.1364 " " 0.0333 "
IV. 0.3214 " " " " " 0.0726 Ag.
V. 0.2361 " " " " " 0.1729 Ag. I.
VI. 0.4016 " " " " " 0.0235 N.

Calculated for		Found.					
$C_7H_8N_3(CH_3)_2I.2AgI.$		I	II	III	IV	V	VI
C	14.23	17.3	17.82	17.61			
H	1.58	1.8	1.77	1.75			
N	5.53						4.99
I	50.20					39.54	
Ag.	28.46				22.58		

The substance from which the above analyses were made, was prepared at different times and purified by treating with absolute alcohol and ether. The wide difference between the calculated result and the results of the analyses, make it doubtful if these two substances are identical. In fact, it is

very doubtful if the formula given by Zinke and Lawson is correct as is indicated by a single analysis made by them.

New Method of Converting Narcotine into Narceine.

As noted heretofore in the old method* for the conversion of narcotine methyl iodide into narcotine methyl chloride, and the subsequent change of this to narceine, involves a treatment with silver chloride, a reaction taking place in which three-fourths of the narcotine methyl derivative changes to the supposed "azoimido" compound, while only one-fourth is changed to the chloride. This means practically seventy-five to eighty per cent loss of narcotine methyl iodide. These facts were an incentive to search for a new method by which a larger percentage of the narcotine could be changed to its methyl chloride, a compound from which narceine is readily obtained. With this object in view, a direct substitution of chlorine for iodine, by treating the iodide with chlorine water, was tried; and from results actually obtained, it proved a far more satisfactory process than the old one.

The following is the new method of treatment: Narcotine methyl iodide was made by digesting the alkaloid with an excess of methyl iodide for several hours. On evaporating off the excess of iodide, the narcotine methyl iodide remained as a lemon-colored amorphous mass, which on treating with water readily changes to an oily substance. A solution of this narcotine methyl iodide in alcohol was treated with a small amount of chlorine water. A light yellow precipitate was formed, which dissolved in the alcohol present. Upon the addition of more chlorine water, it was again thrown down. With a small excess of the reagent, it appeared to grow darker in color, forming a slight scum of gummy substance on the surface of the liquid. On standing a few minutes, the precipitate collected in flakes and settled to the bottom, leaving the supernatant liquid with a brownish tinge. On warming for two or three hours, more of the precipitate dissolved, changing the liquid to a darker brown color. When the precipitate was first formed, it showed no sign of crystallization, but after warming and allowing to stand over night, it was found, on examination with the microscope, to be made up of small prismatic

*Annalen d. Chemie u. Pharmacie 247-169.

needles. These crystals were filtered off and a new lot obtained by treating the filtrate with more chlorine water. The second lot was filtered off and found to be identical with the first. The two lots were united, purified and analyses made, the results of which will be tabulated later on.

Narcotine methyl chloride is extremely soluble in water, so that if formed in the above treatment, it must necessarily be found in the filtrate. The filtrate was therefore slowly evaporated almost to dryness on a water bath, leaving a brownish gum-like substance which gradually changed to a crystalline mass. This substance was subsequently identified as narcotine methyl chloride.

The method was then tried quantitatively with the following result:

I. 2.86 grams narc. methyl iodide gave 1.22 narc. methyl chloride.
II. 3.00 " " " " " 1.39 " " "

Later experiments have shown that a much larger percentage of the chloride may be obtained by using larger quantities of the iodide, thus reducing the relative loss. In this way fifty-five to sixty per cent has been obtained.

In order to identify the substance as the methyl chloride and to determine its purity, a part was converted into the platinum double salt and subjected to analysis. This salt is an amorphous powder slightly soluble in water and readily so in alcohol. When dried it melts at 221° C. An analysis of the substance, dried to a constant weight at 110° C. gave the following results:

I. 0.2090 grams double salt gave 0.0319 Pt.
II. 0.1946 " " " " 0.0298 "

Calculated for $(C_{22}H_{23}NO_7CH_3Cl)_2PtCl_4$	Found. I.	II.
Pt 15.39.	15.27.	15.31.

The pure narcotine methyl chloride, as indicated by the above analysis, was then converted, according to the method of Roser,* into narceine by neutralizing with sodium hydroxide and passing a strong current of steam into it. On cooling, the substance appeared as a mass of fine felt-like needles which were filtered off and identified as narceine. A second crop of crystals was obtained by evaporating the filtrate. The dried substance melted at 172° C.

* Annalen d. Chemie u. Pharmacie 247 267.

Narcotine methyl triodide, ($C_{22}H_{21}I_2NO_7 \cdot CH_3I$).

The formation of the brown substance, above referred to, on the addition of chlorine water showed that the conversion is not by a direct substitution. In order to determine the nature of the reaction, this by-product was examined. When first formed, it melted at 146° C., but when re-crystallized from alcohol and dried, it melted sharp at 149°C. It is almost insoluble in cold water, but it dissolves with difficulty in hot water. It dissolves readily in methyl and ethyl alcohols, from which solutions fine crystals were obtained. It is likewise very soluble in acetone and chloroform, from which it is obtained as a gum or varnish. It is slightly soluble in ether, and insoluble in carbon bi-sulphide. It is readily dissolved in sulphurous acid, from which it can again be deposited in crystals upon evaporation of the sulphur dioxide. The substance contains no water of crystallization. Analyses gave the following results:

I. 0.2082 grams dried substance gave 0.2583 CO_2 and 0.0633 H_2O.
II. 0.1995 " " " " 0.1754 AgI.
III. 0.2036 " " " " 0.1803 AgI.

Calculated for $C_{22}H_{21}I_2NO_7 \cdot CH_3I$.		Found. I	II	III
C	34.25	33.83		
H	2.98	3.38		
I	47.12		47.50	47.84.

From the large percentage found, it is evident that the iodine of the narcotine methyl iodide has been concentrated in this by-product. Thus, one molecule of narcotine methyl iodide has combined with two extra iodine atoms liberated by chlorine in the formation of narcotine methyl chloride. This may be shown by the equation,

$$3C_{22}H_{23}NO_7 \cdot CH_3I + 2Cl_2 = 2C_{22}H_{23}NO_7 \cdot CH_3Cl + C_{22}H_{21}I_2NO_7 \cdot CH_3I + 2HCl.$$

The formation of hydrochloric acid in this reaction accounts for its presence during the evaporation of the liquid. According to this equation, from three molecules of narcotine methyl iodide, two molecules or about sixty-six per cent of narcotine methyl chloride, and one molecule or about thirty-three per cent of narcotine methyl triodide may be obtained. The following determinations sustain this reaction:

I. 3.0 grams narc. methyl iodide gave 0.979 triodide and 1.390 narc. methyl chloride.

II. 5.0 grams narc. methyl iodide gave 1.64 triodide and 2.62 narc. methyl chloride.

As is seen from the above equation, the highest theoretical amount of narcotine methyl chloride obtainable by the new method, is sixty-six per cent, while by the old process it is only twenty-five. This fact, combined with the simplicity of the process makes this new method, in every way, preferable to the old.

[1] Annalen d. Chemie u. Pharmacie 217-167.

THE MOTION OF A BASE-BALL.

C. H. HINTON.

When, in 1878, curve pitching was introduced, there arose a great deal of discussion. In the absence of any notion as to how a ball, left to itself, could change the direction of its course through the air, some went so far as to deny the possibility of the curve; others more open to the results of observation sought for a means of explaining the unfamiliar effect.

Amongst the first in the field was Professor Eddy, of this University. He gave an explanation which we shall reproduce below. His theory has one great advantage: that it accords with the facts; most of the other explanations given at the time had this disadvantage about them: that they gave the wrong direction for the curve of the ball.

Imagine a boat moving with its head pointed to the north; let those oarsmen on the west side pull, those on the east side back water. The boat will tend to the east.

Now if the boat be spherical and the oars be very small, we have an approximation to the case of a ball revolving about an axis. The friction of the surface on the air replaces the stroke of the oars. From this analogy we might suppose that a ball traveling to the north and rotating so that the front of it goes to the west, will tend in an easterly direction.

The reverse is the case. The ball tends to curve in that direction towards which the front of it is moving. If the front is moving to the west it bends away from the north line to the westward. Hence our first analogy is misleading.

Again, another explanation, which was given, is the following, derived from the movement of a billiard ball:

A billiard ball is driven north against a cushion and is hit so as to give it a spin about a vertical axis, the front of the ball going from east to west. When it reaches the cushion it will tend to roll along it, as a wheel would, and it will show in its rebound that this tendency of motion is to the east.

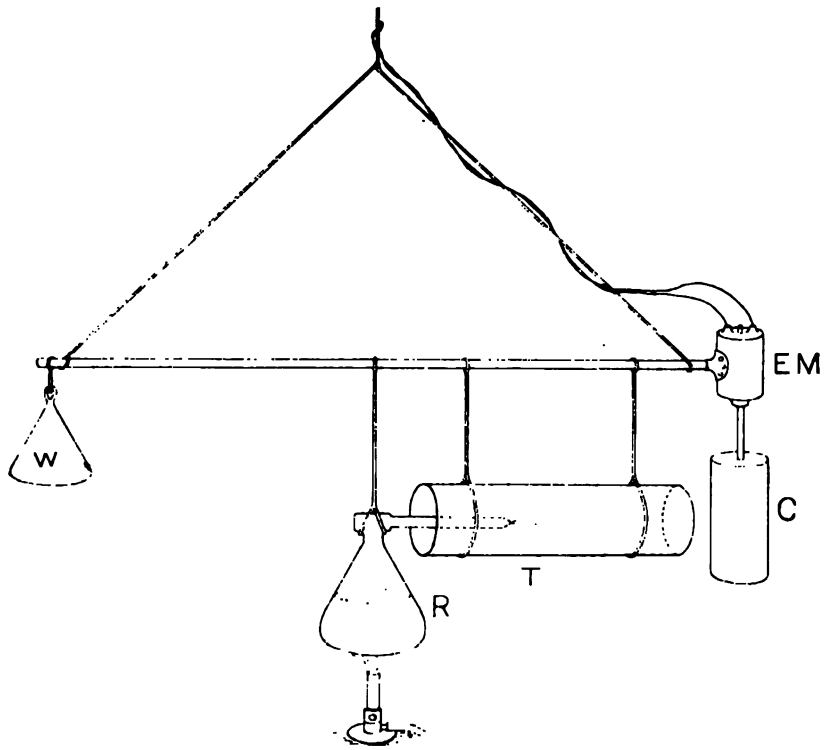
By analogy, consider the air in front of the moving base-ball. It is compressed and forms a sort of cushion. The front

of the ball, revolving from east to west, tends to drive this cushion west and the ball itself will go to the east. Wrong again. The ball goes to the west; the curve takes place to the west.

In the case of a base-ball, moving through the air, there is a difficulty in conducting the observations. Is there any way in which we can reproduce the circumstances so as to study the movement at our leisure?

The question is one of relative velocity. The ball is moving through the air and rotating. We can instead suppose the ball to be kept in one place and a current of air driven past it. Thus if the ball is rotating, the exact circumstances of the inter-play of forces between the air and the ball are reproduced.

A very convenient method of performing the experiment is shown in the accompanying diagram.



At one end of a rod is an electro-motor, EM., to the shaft of which is attached a cylinder. The cylinder rotates about a vertical axis and, although not a sphere, reproduces the conditions as far as lateral motion is concerned, which hold in the case of a sphere.

Attached to the rod is a large tube, in which is introduced the jet from a retort. When steam is generated in the retort a strong current of air is hurled along the length of the tube and directed on the cylinder.

The current of air thus generated replaces the effect due to the resistance of the air when the ball is projected through it, while the rotation of the ball is effectively represented by the rotation of the cylinder effected by the electro-motor. The rod is suspended to the ceiling by a fine wire, and the leads to the electro-motor are so disposed that their torsion will produce but a slight resistance to the turning of the rod about its middle point.

If now, in the arrangement as described, the electro-motor be set to work, there is no movement of the system. If the electro-motor be stopped and a current of air be generated, there is also no movement. If, however, both the cylinder rotate and the current play, the whole system begins to revolve slowly on its axis.

Thus it shows that when a rotating cylinder lies in the path of a current of air, there is an unsymmetrical result produced. More pressure exists on one side than on the other. Assuming that the tube lies to the north of the cylinder, and the front of the cylinder rotates from east to west, the end of the rod bearing the electro-motor turns to the west. Thus showing that the same conditions are reproduced as when a rotating ball meets a current of air due to its own velocity.

In order to explain this effect, we must have recourse to the study of currents of fluids. Now the behavior of streams of liquids is difficult to understand, because it is very different from the behavior of streams of people. When we come out of a theatre or any crowded place from a broad to a narrow way, we expect to find a jam, to undergo considerable pressure.

But people are different from the particles of a liquid. People have the means of setting themselves in progression;

the particles of a liquid only move when the pressure behind them is greater than that in front of them.

Suppose there is a narrow place in a tube; if the movement of the liquid is steady, the rate is slower in the wide portion than in the narrow portion. Since the same quantity of liquid passes each section of the tube in the same time, where the section is small, the velocities of the particles must be greater than where the section is large.

Now the only way in which the particles can be made to go faster is by having the pressure in front of them less than the pressure behind. Consequently, in the narrow section and where it is narrowing, where the velocities of the particles are increasing the pressure must be less than in the wider portions of the tube. Experiment shows that this is the case. If narrow gauge tubes are introduced into the sides of a channel containing flowing water, the height of the water in the gauge tubes is greater where the diameter of the channel is large, and less where the channel is narrow.

It suggests itself as a corollary that where people are emerging in a throng from a crowded building, they would find their exit made more speedy and less uncomfortable by turning round and letting the current carry them backwards.

Consider now on which side of the rotating cylinder the current is speediest. Referring to the first diagram, which will serve for the section of the cylinder, it is obvious that on the west side, where the current produced by the rotation of the ball aids that of the infringing air, the velocity is greater than on the other side, where the current produced by the ball meets and counteracts the current of the infringing air. But where the velocity is greater, the pressure is less—it must be so, for only where there is a region of less pressure is velocity increased. Hence, there is less pressure on the west side of the cylinder, and the whole system will swing so that the cylinder travels to the west. In like manner, when the ball is spinning and traveling through the air, in the manner indicated in the diagram, it will tend to the west.

The mathematical treatment of this question, by Professor Eddy's method, and by means of stream lines, will be deferred

for the moment, for the sake of a different aspect of the problem.

It being acknowledged that a ball projected in the air will curve if it spins about an axis perpendicular to its line of progression, how can an instrument be devised which shall impart these two simultaneous movements—one of translation, the other of rotation.

The means by which a spin about the axis of projection is effected formed a very important step in the modern development of fire arms, but the production of the other kind of spin, in a ready and simple manner, has been left, until late years, to the dexterity of the pitcher.

There are some pieces of experimental apparatus in which, for the sake of showing the curve effect, a ball is rotated rapidly, then hit a sudden blow.

In taking up the problem it naturally occurred to me to combine two pieces of machinery in one, firstly, to produce a spin in the ball and to combine this with a rapid motion of projection. The first attempt was made with a catapult on which a rotator was carried.

On a long shaft a strong spring propelled a slide. The slide carried a vertical pillar with a free collar on which were hinged three curved rods. The extremities of these rods embraced the ball and were held in position by a cord wrapped many times round them. The cord thus acted like a string round a top. When the slide was propelled by the spring, the string being fixed at one end, the collar was obliged to rotate to allow the string to unwind itself. When the string was unwound the rods flew apart by centrifugal velocity. Thus a ball was delivered with both rotary and translatory movement. The objection, however, to this apparatus was the same as to those theories I have previously mentioned. It made the ball go in every direction but the right one. It became apparent that the practical method was to produce a good quick ball and then devise some means of turning a portion of its velocity into spin, transforming, as in the rifle, a portion of the momentum into rotation, but about a different axis. Accordingly, I had a small cannon cast. By the use of powder any degree of velocity of projection was obtained and various devices were tested.

Studs were placed in the barrel, strings were wrapped round the ball inside and outside the barrel. But the desired effect failed to appear.

Finally, however, a very obvious consideration presented itself. The pitcher sends curved balls and his method can be imitated.

The motion of rotation, as is well known, is imparted to a pitched ball, by means of the fingere. These clasping the ball somewhat, arrest its onward motion and give it the rotation required.

In the rim of the mouth of the cannon, some holes were bored, straight iron rods were inserted, and made to increase in diameter towards their extremities by a wrapping of string.

Those first tried were about an inch apart and produced no visible effect. But on extending the width between the two fingers, an unmistakable deflection was observed. The ball diverged from the straight course in the direction of that side on which its motion was impeded by the friction of the fingers.

Subsequently it was found that soft rubber was the best covering for these artificial fingers. They can be made of any curvature and length—those 6 inches long and projecting at their extremities about ¾ of an inch into the continuation of the barrel work very effectively.

This result was interesting, but there were two obstacles still to be overcome before the gun could be used. The one was a psychologic difficulty, the other concerned life and limb.

Fired, as the cannon was, by means of a small charge of powder close behind the ball, the velocities were very irregular—sometimes prodigious, sometimes insufficient.

It was necessary to discover a means of driving the ball with uniform speed, of controling the action of the powder.

A long succession of experiments showed that as the tubes in which the powder was exploded increased in length, the propulsion of the ball became more regular.

Finally, with a tube five feet long, and .38 of an inch in diameter, a charge of 23 grams of powder was found to drive the ball with regularity and accuracy. The tube employed does not proceed directly out of the body of the gun, but is enclosed by a second tube, which leads the gases generated by the explosion

into the barrel in such a direction that they do not hit the ball directly.

By sliding the first tube in and out of the second, a variation in velocity is obtained. Thus, danger to life and limb is avoided. The psychologic difficulty proceeds from the fact that the ball is delivered from the gun without warning. There is no preliminary motion, as in the case of the pitcher's arm, to give an indication of when the ball sets out on its course.

To overcome this, the batter is enabled to discharge the ball himself.

He is provided with a plate or trap. When he presses his foot on it he breaks an electric current, a spring is released, which pulls the trigger in its contraction, and the gun is discharged.

The foregoing are the chief features of the mechanism for projecting a curved ball, and although they are inferior in interest to the scientific principles on which the curved motion depends, still as having been the occasion of a certain revival in base-ball in this University, they may be received with indulgence by the readers of the YEAR BOOK.

Professor Eddy's explanation of the curved trajectory of a rotating sphere is as follows in outline:

At a given moment any rigid body, whatever its motion, may be conceived as rotating about some axis. This axis changes its position, but, for the moment, relatively to the solid body, it is at rest.

If the base-ball has a velocity of rotation so great that one point of it is at rest as the point of a wheel in contact with the ground is at rest momentarily, while the wheel rolls on over it, this point is the instantaneous centre.

Imagine the base-ball to be proceeding with such speed and rotating so fast that a point in the circumference of the ball is at rest, then at that instant, the direction of movement of every particle of the ball is at right angles to the line joining it to the instantaneous centre on the circumference.

Let A be this point and consider two small areas, B and C, symmetrical with regard to the line of the centre but C nearer to A. B is being urged through the air with greater velocity than C, and will, therefore, be the occasion of greater pressure reacting on the ball.

Professor Eddy has integrated the pressures thus resulting over the whole surface of the ball and finds that there is a resultant pressure tending to deflect the ball in the direction in which the front of it is moving.

The explanation, by means of stream lines in which, for the sake of simplicity, a cylinder is taken in place of a sphere, is as follows:

By the simple experiment of spinning a heavy ball and letting it fall into a vessel of water, it can be shown that the deflection does not depend on the compressibility of the medium. A ball so started presents a remarkable instance of the phenomenon under discussion.

Let a cylinder, $x^2 + y_2 = a^2$, with angular rotation w, be immersed in a liquid having velocity $\frac{dy}{dt} = -V$. The stream and potential functions of the liquid alone are given by

$$P + iQ = Az.$$

The stream and potential functions of the liquid in the neighborhood of the cylinder, which shares its motion of angular rotation, can be, for its part, represented by

$$P + iQ = \log z.$$

Now as the motion is not symmetrical introduce another function Bz^{-1} which represents stream lines touching the ones of y, and put for the stream lines and potential functions of the system

$$P + iQ = Az + Bz^{-1} + C \log z$$

For the boundary condition since the motion is steady

$$\frac{d}{dt}\left\{x^2 + y^2\right\} = 0$$

$$xu + yv = 0$$

the radial component is zero and the velocity is altogether tangentral at surface of cylinder.

We have taken beside the function for the liquid, for the cylinder and concentric rings,

$$P + iQ = C \log. z.$$

The set of eccentric flow lines must simply be added,

$$P + iQ = B : z.$$

which gives for the sum of the conditions

$$P + iQ = Az + B\bar{z} + C \log. z.$$

Transforming to polar co-ordinates and separating, we have

$$P = A r \cos\theta + B \cos\theta \div r + C \log. r.$$

$$Q = A r \sin\theta - B \sin\theta \div r + C\theta.$$

For the velocity at the surface

$$\frac{dP}{dr} = A \cos\theta - B \cos\theta \div r^2 + C \div r.$$

$$\frac{dP}{r d\theta} = -A \sin\theta - \frac{B \sin\theta}{r^2}$$

When $r = a$, the normal velocity is zero.

Therefore,

$$-A \sin\theta - \frac{B \sin\theta}{r^2} = 0.$$

Therefore,

$$B = -a^2 A.$$

Consequently,

Tangential velocity $= A \cos\theta (1 + a^2 \div r^2) + C \div r.$

Normal velocity $= -A \sin\theta (1 - a^2 \div r^2).$

The velocity in direction of $+ y$ is

Tangential velocity $\times \cos\theta$ — normal velocity $\times \sin\theta$

$= A + A \cos 2\theta a^2 \div r^2 + C \cos\theta \div r.$

As r becomes great this approximates to A. Hence, put $A = -V$ and let $C = wa^2$, where w is the angular velocity of the cylinder.

Hence, tangential velocity $= -V \cos\theta (1 + a^2 \div r^2) + \frac{a^2 w}{r}$

" normal " $= V \sin\theta (1 - a^2 \div r^2).$

Since there are no external forces, we have p being the pressure and Q the velocity, R the density.

$$\int \frac{dp}{R} = -\frac{1}{2} Q^2 + C.$$

Since the effect remains with incompressible fluids, let $R=1$.

Therefore,

$$p=-\frac{1}{2}Q^2+C.$$

$$=-\frac{1}{2}\left\{V^2+V^2a^4\div r^4+2a^2V^2\cos 2\theta\div r^2\right.$$

$$\left.-2a^2wV\cos\theta\div r^2\left(1+\frac{a^2}{r^2}\right)+\frac{a^4w^2}{r^2}\right\}+C.$$

Now let p at $\infty=\frac{1}{2}V^2$.

Therefore, at ∞ $\frac{1}{2}V^2=-\frac{1}{2}V^2+C.$

Hence, finally

$$p=\frac{1}{2}V^2-\frac{1}{2}V^2a^2\div r^4-a^2V^2\cos 2\theta\div r^2+a^2wV\cos\theta$$

$$\left(1+\frac{a^2}{r^2}\right)\div r^2-a^4w^2\div 2r^2$$

and if $r=a$,

$$p=-V^2\cos 2\theta+2wV\cos\theta-\frac{a^2w^2}{2}$$

This pressure acts normally to the stream line surface of the cylinder. Hence, pressure on one side $=$

$$\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}p\cos\theta a d\theta.$$

the other $=$

$$-\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}p\cos\theta a d\theta.$$

Replacing p by its value and intergrating, we get:

Pressure on one side,

$$2aV^2 - \frac{4}{3}aV^2 + waV\pi = -\frac{a^3w^2}{2}$$

Pressure on the other,

$$-2aV^2 + \frac{4}{3}aV^2 + waV\pi = +\frac{a^3w^2}{2}$$

of which two expressions the terms are contrary in sign except in the case of $waV\pi$.

Hence the pressure will balance except for a resultant pressure of $2\pi awV$ tending to defend the cylinder to the negative direction on the x axis.

Consequently, the deflection observed can be represented mathematically.

A FEW QUERIES.

GEO. D. SHEPARDSON.

The following questions from various sources and upon divers subjects are offered as food for thought and possible investigation. The solutions for some may be found in books or papers, others may be found by interrogating nature, while others may remain unsolved. One purpose in making the queries is to suggest to the student who may be afflicted with the idea that he has mastered his studies and all connected therewith, that "there are many things that the Sophomore's philosophy never dreamt of" and that he need not be in too great a rush to finish his course lest, perchance, there may be no fields left unexplored in which he may win laurels for himself. In every branch of physics are many points of interest to hold one's attention and curiosity. He may prevent or cure ennui by delving into sound, light, heat, mechanics or electricity.

Why does a male quartette sound better to most people's ears than a mixed quartette of equal ability?

Why does a male quartette usually sound better without than with an instrumental accompaniment?

Why is it that a close chord will please the ear when struck on the upper registers of a piano or organ, while the same chord struck on the lower registers or bass keys will seem to be discordant?

Why do tunes played in sharps seem to be more lively or vivacious than when played in flats?

Why does a quartette, that usually gets lower and lower when singing without an accompaniment, find it easy to keep up to pitch if the tune is changed to a key one-half step higher?

Why do voices harmonize better and better as they practice together more and more?

Why does the pitch of organ pipes of the same length depend upon the area or cross-section of the pipe?

Why does the quality of the sound of an organ pipe vary with the section?

When an organ pipe is overblown, why does it sound not the octave but a tone about a seventh above the fundamental?

A bell usually gives a complex sound made up of many components. Why does one tone and then another seem most prominent as the listener changes his location?

The most prominent sound from the bell seems to change not only with the distance, but also with the nature, size and location of intervening objects. How can this be accounted for?

The pitch of the bell on a locomotive seems to rise an interval of about a fifth when the engine passes behind a building or hill. Explain.

The pitch of a bell or whistle seems higher when approaching than when receding. What determines the amount of change of pitch?

Why does the pitch of a bell seem to rise and fall by an interval of about a third as the bell swings to and fro?

On a brass wind instrument, such as a tuba, one with the practice and "know how" can make the fundamental tone of the pipe, which is an octave lower than that usually sounded as the lowest open note. Theoretically he can make no open tone between the two, but by practice he can make another tone about midway between the two. For example, on an E Flat tuba one can sound the E Flat written on the first added line below the staff and with practice can also sound the tone one octave lower. If he has the right kind of mouthpiece he can also make a "false tone" on A Flat between the two tones mentioned. If he can make this tone, he can then make the whole gamut between the two by using the keys. How can this "false tone" be accounted for? Not by any common theory.

Again if the tuba player has a good mouth piece and a good "lip," he can play the whole lower gamut without touching a key; in fact he can play a simple tune by skilful operation of his lips alone without touching a single key. How can this be explained?

With a good instrument and practice, it is possible to make two tones at once on the tuba an octave apart, or sometimes with an interval of the fifth. Thus one can play a sort of duet on a single pipe.

It sometimes occurs that a clock that keeps correct time when in a watchmaker's shop will not run accurately when set up in another place. Could it have been influenced by some action of the other clocks forcing it into synchronism when in the shop?

When writing with a pen, why does the ink leave the pen and go to the paper?

Why can one tell whether ink on the paper is dry by looking at it aslant to see if it still shines?

Why will two pieces of fresh apple stick together more firmly when cut with a knife than when broken apart?

Why do two pieces of glass stick together when wet?

Why does a razor shave better if the edge is first dipped in hot water?

Why will a razor that has lost its edge or temper regain the same if put away and left unused for a time?

Why do millers believe that water-wheels run faster at night than in the daytime?

Why do washerwomen claim that hot water will soak up a leaky tub quicker than cold water?

Why does a heavy Pullman car ride easier than a short, light day coach when going around reverse curves?

Why does a locomotive with boiler set high above the wheels seem to ride easier than one with boiler set low?

Why does a train running on a straight track ride easier as the speed increases?

How do the effects of low rail joints vary with the speed of the passing wheels?

For an electric car not intended to be operated in a train, what determines the best position for the trucks?

How is this position affected if the car is to operate in a train?

Why are the trucks on the Interurban cars pivoted not centrally between the two axles, but nearer one than the other?

If one truck is pivoted near the front axle, is the other likewise, or is it pivoted nearer the rear axle?

Why is a short wheel-base desirable? Why is it not?

Why do railway trains take the left track instead of the right?

Why do street cars differ from steam cars in this respect and take the right track?

When two passenger trains meet on a single track road what determines which train shall take the side track?

Why do engineers say that when a locomotive is running forward her engines are running backward?

Suppose one fastens a rope or strap to a spoke of one of the wheels of a wagon, then gets into the wagon and pulls the rope. If the rope is fastened to the spoke below the hub, the wagon moves in a direction opposite to that in which it would have moved if the spoke had been over the hub. Why is this?

If one stands on the ground and pulls, the direction of motion of the wagon is independent of the position of the spoke. Explain.

In which position of the connecting-rod of a locomotive is slipping on the track most likely to begin in case of heavy loading?

Why does the pay of locomotive engineers vary with the number of driving wheels on the locomotive?

Why can an electric locomotive pull a heavier load without slipping than is possible for a steam locomotive having an equal weight on the drivers?

What determines the grade of the steepest smooth road down which one can ride a bicycle and control his speed by back-pedalling without using his brake? What elements complicate the calculation?

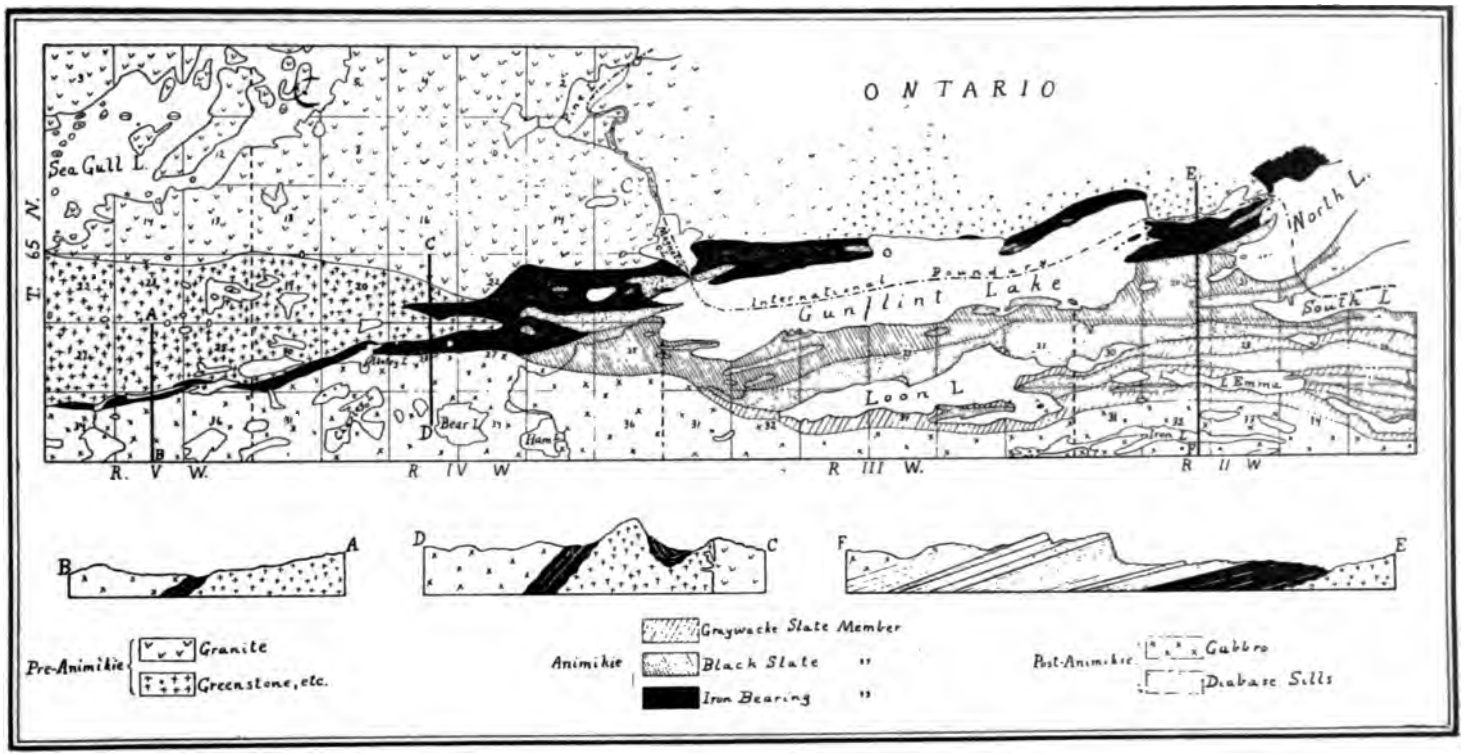
Is this the same as the limiting grade up which he can propel his machine?

What element of truth in the statement that the summer days are longer than winter days because the heat of the sun expands them?

Why does a lamp chimney become blurred for a short time when a lamp is lighted?

Why does a so-called hot air furnace refuse to warm rooms on the windward side of a house even if storm windows are on?

Why does the furnace have difficulty in getting cold air supply when the wind is strongly from the side of the house where the intake pipe opens?



GEOLOGICAL MAP OF THE MESABI IRON RANGE IN COOK COUNTY, MINNESOTA.

Compiled by U. S. Grant from field notes of the Geological and Natural History Survey of Minnesota. The data for the geological boundaries on the Canadian side of the map are very incomplete. The horizontal scale of the sections is twice that of the map, and the vertical scale is several times that of the horizontal scale.

How do the candlepower and efficiency of an incandescent lamp vary with the surrounding temperature?

How are these affected by the shape of the cross section of the filament?

How are these affected by the shape of the alternating current curve?

Is the intrinsic brilliancy or candlepower per unit area equal in different directions from a flat gas jet? If unequal, does it indicate that the flame is not a solid mass of incandescent material, but rather composed of fine particles separated by comparatively small spaces?

When an arc light throws a sharp shadow the main shadow is outlined by a narrow border much brighter than the average illumination, this bright border being surrounded by a dark line. If the bright and dark borders are due to interference, why is not each a series of prismatic colors rather than white and black?

Suppose the two lights on a photometer are a definite distance apart, say 300 centimeters, how can one calculate the position of the screen for 16 candle power?

How is the law of inverse squares for the photometer affected by the fact that the incandescent lamp or the arc lamp with globe is not a point but has a surface of appreciable area?

The static electricity frequently observed about a rapidly moving belt is variously attributed to slipping on the pulleys, to the bending of the belt in passing around the pulley, and to the friction against the air. How can one determine the extent to which these causes are effective?

Dry rot on grapes and blight on pears are sometimes prevented by enclosing the fruit in paper bags. Is the real function of the bags to insulate the fruit from the direct effects of the atmospheric electricity? If so, would equal or better results be obtained by enclosing them in wire screens?

Is the apparent barrenness of the soil directly under pine and cedar trees due not so much to the dead needles covering the ground as to the effect of the many sharp points of the needles on the trees discharging the electricity of the air and thus devitalizing it?

Is the function of the many spines or sharp points on the

edges of leaves to assist in appropriating the electricity of the air?

The ground detectors commonly used for indicating the insulation resistance of alternating current lines, consist of a small transformer having a lamp or voltmeter connected with the secondary circuit. One terminal of the primary is connected with the earth while the other terminal may be attached to the potential circuit. The deflection of the voltmeter needle or the lighting of the lamp is taken as an indication of the existence and resistance of the ground on the circuit. But since the line has more or less capacity and since the potential of each wire is alternately higher and lower with respect to the earth, an alternating current will pass through the primary of the testing transformer, which current is proportional to the capacity of the line, the frequency and voltage of the current. Such a current will exist even if the insulation is practically perfect. How can such indications be interpreted quantitatively?

What is meant by a positive charge or a negative charge of electricity? The action of the electro-static voltmeter or electrometer is usually explained by saying that the needle and the stationary vanes are oppositely charged and therefore attract one another, the force being proportional to the capacity of the system and to the difference of potential between the two parts. Now suppose a static voltmeter to be connected to a battery, of say 500 volts, whose middle point is grounded; one terminal of the battery will then be positive with reference to the earth while the other terminal is negative; according to the common theory the two parts of the voltmeter are oppositely charged with a difference of 500 volts and attract each other with a certain force. Next suppose the voltmeter is left connected as before, but the battery is grounded at one end, say the negative, instead of at the middle point; one side of the voltmeter is now at the potential of the earth, or zero, while the other is at a potential of 500 volts above. Can there be attraction between the two parts when the potential of one is zero? Suppose again that the battery is grounded at the negative end, but that the negative terminal of the voltmeter is connected to a point of the battery 10 volts from the end; then the difference of potential between the two parts of the voltmeter is 490

volts. Since both parts of the static voltmeter are positive with reference to the earth, there can be no attraction, but rather repulsion, and the static voltmeter should indicate some negative voltage, the pointer moving back past zero. In other words, according to the common theory, although a difference of potential practically the same might exist between the parts of the voltmeter, the voltmeter might show a positive, or a zero, or a negative reading according to the point of the battery to which the wire was attached. Does any believe this?

An electromotive force is sometimes measured by charging a condenser and then discharging it through a ballistic galvanometer, the electromotive force being calculated from the "kick" or throw of the galvanometer needle. In order to adjust the sensitiveness of the galvanometer, students occasionally try varying the resistance of the galvanometer circuit. They get all sorts of results. Changing the resistance seems to have no effect whatever upon the throw of the galvanometer needle, until they reach a certain point above which an increase of resistance begins to diminish the throw, and it then varies more or less closely in inverse proportion to the resistance of the galvanometer circuit. How can this be explained? What determines the critical value of the resistance for a given galvanometer?

The range of a static voltmeter may be increased by connecting a condenser in series, as an electrodynamic voltmeter may be affected by connecting a resistance in series. The resistance of the latter is approximately constant, so that the added resistance simply gives a multiplier to the indications of the voltmeter. But the capacity of the electrostatic voltmeter varies according to the position of the needle. How can the multiplied values of the static voltmeter readings be calculated?

An electrostatic voltmeter may give reliable readings even if its insulation is not perfect. In fact some instrument makers purposely make the insulation somewhat low in order to avoid troubles from electrostatic induction or from static charges on the glass or elsewhere. What will be the effect upon such an instrument of connecting a well insulated condenser in series?

How can the condenser be arranged to give concordant results with such an instrument?

Why do central station men believe that the amount of trouble experienced from lightning varies directly with the working voltage of their circuits?

Explain how capacity in a circuit causes the current to be in advance of the electromotive force. How can the current have a real value when the EMF is zero?

A condenser is said to have an infinite capacity when its plates are in actual contact so as to make the circuit continuous. In such a case, what value does the angle of lead take?

When the apparent watts in an alternating circuit, as measured by ammeter and voltmeter, differ from the actual watts as measured by a wattmeter, how can one tell experimentally whether the current lags behind or leads the EMF?

Under what conditions and why is the output a maximum when the angle of lag is 45 degrees?

In a rotary transformer, why is the alternating EMF not the theoretical percentage (70.7) of the continuous EMF, but something different? Why does this ratio vary according to the position of the brushes? To what extent can the ratio be modified by shifting the brushes?

How can the counter EMF of a synchronous motor be higher than the impressed EMF?

To what extent does a rotary transformer act as a synchronous motor? Can its counter EMF be much greater than the impressed?

In the case of a rotary transformer supplied with alternating current at constant pressure, what determines the best excitation for the field circuit? If the rotary acts as a synchronous motor and therefore runs at constant speed, how is the continuous current pressure affected by changes of field current?

In a single-phase rotary transformer there is a direct connection between the brushes of both continuous and alternating current sides at certain parts of each revolution and at these points there is no transformation of the energy. At other points the energy is transformed. The rate at which energy is supplied from the alternating circuit varies at different parts of

each cycle, being zero when either the current or EMF passes through zero. On the continuous side, however, the energy is uniform throughout the revolution. What becomes of the surplus and whence the deficit? Is the continuous current pressure strictly uniform?

How does a three-phase rotary compare in above respects with single phase?

Since the energy supplied to a single-phase A. C. motor varies through each cycle, does the speed of the armature vary also in different parts of each revolution?

When a rotary transformer is used for supplying a railway line, what effects do the sudden and great changes of load have upon the speed of the rotary? If it slows down the rotary, does the generator supplying the rotary also slow down in unison? What if the same generator supplied several rotaries each of which fed into different circuits so that the loads on the rotaries did not vary simultaneously?

An electro-dynamometer measures the square root of the mean of the squares of the instantaneous values of the current passing through its coils, while an instrument of the d'Arsonval type having a coil moving in the field of a permanent magnet measures the average value of the current. Suppose current from a battery is sent through one dynamometer, then through a d'Arsonval ammeter, then through a revolving commutator and through another dynamometer, then back through the commutator and to the battery. Will the three instruments agree?

Suppose that current from an alternator giving a sine current is sent through an electro-dynamometer, then through a rectifying commutator and through a second dynamometer and a d'Arsonval ammeter, then through the commutator and back to the alternator. Will the three instruments agree?

According to the elementary theory, the torque of a plain series motor should be constant when driven by a constant current. As a matter of fact the torque does vary according to the load applied. How can this be explained?

What determines the speed of a series motor on constant current circuit?

If a shunt motor without load is rapidly started on a con-

stant potential circuit, the speed rises to a point considerably above normal and then slowly drops back to normal speed. How can this be explained?

Why does a ring armature usually spark more than a drum armature?

How do commutator compounds reduce sparking?

What determines the best relative widths of copper and mica in a commutator?

In the operation of a dynamo or motor, two kinds of spark may be observed. The white spark looks vicious but does not cut the commutator much; the red spark rapidly destroys both commutator and brushes. How can both kinds of spark exist on the same machine? What is the real difference between the two kinds of spark? What is the cause of each?

What is the real cause of the electro-motive force induced in an armature? What difference between "cutting" lines of force and changing the number of lines enclosed by the circuit? How can the torque be explained when the armature conductors are in slots or holes in the armature core?

What is meant by a "bucking" motor? Causes of bucking?

What determines the choice between the words "electric" and "electrical?"

Explain the explosive noise observed when a dynamo is short-circuited.

What causes the noise when a fuse blows?

What causes the hissing noise sometimes observed when a switch is closed on a 500 volt circuit?

Why will a magnetic switch open more quickly if the magnet coil is short-circuited than if the circuit is opened?

If lines of force tend to take the shortest path, why do not all the lines take the shortest path between the poles of a magnet and leave no stray field around the longer paths?

Is there something traveling along the lines of force? If not, why do they take the easiest path?

Are the lines of force about a conductor actually increased in number by the presence of iron, or are they simply gathered to the iron, leaving the remaining space less magnetized?

How does the magnetic field about an iron conductor compare with that around a copper conductor?

In the case of a long solenoid, the reluctance of the return is considered as negligible because of the spreading of the lines of force and to the consequently large area of the path. What would be the effect of bringing iron near the solenoid, or of enclosing the solenoid in an iron tube?

In calculating the ampere turns for the field coil of a dynamo, what provision is made for the leakage field?

Do the field coils affect the leakage from the sides of the cores of the field magnet? Is the leakage co-efficient affected by the location of the coils?

Is the magnetic leakage from edges and corners due simply to the larger surface, or is it due to a heaping up of the magnetism as static electricity is accumulated and discharged by points?

If no energy is required to maintain a magnetic field, why the necessity of continuing the current through the field coils of a dynamo after the field is magnetized?

A permanent magnet is said to lose some of its strength when heated and to regain it when cooled. What becomes of it, or whence the increase on cooling?

A shunt dynamo having a normal output of 400 amperes at 5 volts is connected in series with a second dynamo having a normal output of 5 amperes at 125 volts. Assuming an efficiency of 80% for each machine, the first requires 2,500 watts, and the second 781 watts or 3281 watts for the two. But would not putting the two in series give a combined output of 400 amperes at 130 volts, or 52,000 watts? A motor of 80% efficiency would drive the two machines by taking 4,200 watts, leaving 47,800 watts as clear gain. Why is this not a great improvement over Pennock's volt-distributor or Keely's motor?

In the above combination, would it make any difference whether the 400 ampere machine were connected to the positive or to the negative side of the 125 volt machine? Would not the voltage of the 400 ampere machine be actually raised to 130 volts if its negative terminal were connected to the positive terminal of the 125 volt machine, the negative terminal of the latter being connected to the earth?

If the armature of a separately excited motor is connected to a series dynamo and the resistance in the circuit is properly

adjusted, the motor armature will run first in one direction and then stop suddenly and run in the opposite direction, this reversing being repeated so long as desired. If the resistance exceeds a certain limit, the motor will continue to run in either direction according to the direction first taken. If the resistance is then reduced a certain amount, the motor will run in one direction, then stop and go ahead in the same direction. The two preceding results may be obtained also by adjusting the field strength of the motor. When the motor is running slowly in one direction, if one holds it back by friction on the pulley, the armature pulls harder and harder. But if one pushes so as to make the armature go faster, it will soon reverse and go in the opposite direction. The complete explanation of the above will give food for considerable thought.

RECLAMATION OF WET LAND IN THE RED RIVER VALLEY.

W. R. HOAG, STATE DRAINAGE COMMISSIONER.

Water, Nature's great solvent, seems wisely to have been provided in sufficient abundance to fulfill readily all its varied missions. Rainfall, Nature's great distillation, whence comes the water for all the land, is supplied to most parts of the land with surprising uniformity, most parts of the earth's surface receiving a fair share of her bounty. Some portions, however, seem to be thrice blessed, while others are denied her bounty altogether. Sections of the west coast have a mean annual rainfall of ninety inches, while the great Mississippi valley finds abundance in one-third this amount.

Man is able and usually willing to accommodate himself to the conditions obtaining with these varied degrees of moisture. But when he finds thousands of acres of rich soil needing but Nature's moist breath to bring it to life and fruitage; or when he sees large tracts of naturally productive land lie cold and barren, simply on account of an over-abundance of water, he revolts and the engineering instinct in him at once sets to work to supply the needed water to the former and to rid the latter of its excess.

Problems relating to the drainage and the protection of lands from river floods and from the sea, as well as general questions of water supply, have been among the earliest to exercise the constructive genius of man. They remain today among the most serious and momentous questions with which the engineer has to deal.

The Romans, while in possession of England, constructed embankments along the principal rivers to protect the adjacent lands from freshets. Over two hundred miles of embankments have long been in use to protect the English coast of Essex. Some of the most valuable portions of Holland have been recovered from the alluvial deposits of the rivers Meuse, Scheld and Rhine. The Russians have for several years been engaged in draining the Pinsk marsh, which comprises about 7,000

square miles. Several thousand miles of ditches will be required to convert the marsh into tillable land. Large areas along the lower Mississippi river have been converted into fine farming land by the many miles of levees which protect them from the overflow of the river. To come nearer home, Illinois has reclaimed considerable worthless marsh land by surface drainage.

The Red river valley furnishes a prominent example of a naturally rich soil rendered of doubtful value by the overflow from spring freshets and summer rains.

MUSTINKA (SHOWING FILLING UP OF DITCH).

A railroad journey up this valley, in the summer, from Morris to Breckenridge, or from Glyndon to Crookston, to the average traveler will present little else but limitless fields of grain or broad stretches of virgin prairie. There are, however, features serving to break this monotony which will attract the quick eye of the engineer. We refer to these state ditches. The word canal conveys the truer idea of their general character,

but the term is technically correct, since their only function is to remove excess water.

The line of the Great Northern Railroad crosses such ditches near Norcross, Tintan, Averill, Felton Bohap, Ada and Kennedy. Seen from the car window, glistening in the sunlight, they stretch away in narrowing lines like ribbons of silver in fields of gold.

When we see engineering skill and business enterprise harnessing the forces of a Niagara and transmitting its hitherto wasted energy to distant points; when, by the hand of the engineer the sea is driven back and forced to yield ground held captive by it for a thousand years; when the skill of the engineer, allied with capital, accomplishes these feats and a thousand others equally great, need we wonder that two million acres of rich soil in the Red river valley needing but riddance from storm water to be at once doubled in value, should present an inviting field for his activity? May we not rather, justly criticise him for so long neglecting this crying demand for his services? The lack of organization among the many individual interests involved and the absence of any legislation regulating such works in this state are largely, if not wholly, responsible for this evident tardiness.

The necessity of some united effort which would insure the proper drainage of large areas of valuable wheat land in this valley has long been recognized.

This region—the home of "No. One Hard"—is about 225 miles long and 30 miles wide on the Minnesota side.

A word as to the general lay of the land in this valley will bring us to a better understanding of the real situation and show at once the entire feasibility of a complete system of drainage such as is now being carried out. We may consider the Minnesota side of the valley as made up of three planes of one water-shed. All these have a slight drainage toward the rorth, the same as that of the Red river itself, which is about five inches to the mile on the lower 300 miles of its length along our Minnesota border. These planes are distinguished by the difference of their slope toward the Red river and are about ten miles wide and of the same length as the valley.

Now, the western plane, that adjacent to the Red river, has,

for the most part, sufficient slope to the west to rid itself of its excess storm water. As might be expected its water courses are ample and well defined and damage from overflow of these streams is uncommon and not at all serious.

The eastern plane has even better drainage, being the slope of the bed of old Lake Agassiz and its streams deliver the storm water easily to its own western boundry.

But the middle section—what of it? Its natural slope is from a few inches to a foot or two per mile. This is practically nothing since small streams cannot maintain their course with this slight fall. The small velocity developed is not sufficient to keep the channel open by the natural action of erosion and the counter action of sedimentation soon obliterates all traces of the water course.

Just this has resulted in this unfortunate middle third area. No small streams cross it and the few large ones which do are a menace rather than a safeguard in time of flood, for the small available slope is consumed in bends and consequent longer route, so that when the extra demand comes an overflow is the result.

Being thus deprived of this usual method of speedy removal of storm water, this middle section must dispose of it by the slow processes of infiltration and evaporation. This it is able to do to a great extent, since the somewhat less rainfall than in other parts of the state and the depth and quality of its rich soil each contribute to this end. But this is not the real difficulty. It receives, in addition to its own storm water, that from an equal, or even a larger, area lying to the east, through numerous small streams which, upon approaching its eastern border, loose themselves by spreading out over the prairie. After weeks of aimless wandering they finally collect their remaining waters and join the Red river by streams through the western belt. We need not dwell upon the serious obstacle which these conditions present to a profitable cultivation of this naturally fertile region.

The first practical move toward a solution was made in 1886 when a convention was held at Crookston to formulate a plan of action. It was attended by delegates from Marshall, Polk, Norman, Clay, and Wilkin counties, and the proceedings

were characterized by earnest and intelligent discussion and wise action. It was decided that an accurate topographical survey was first needed, and ten thousand dollars was raised at once to meet the expense of the survey.

Mr. J. T. Fanning, the well known hydraulic engineer of this city, was made consulting engineer, and Mr. C. G. Elliott was given immediate charge of the field work. The survey was completed and an exhaustive report submitted, establishing the complete feasibility of the plan and defining what ditches were needed and indicating, in general, their location. It called for about 275 miles of main ditch, costing about $750,000.

The first plans and estimates of the engineers have proven to be very accurate and trustworthy as to position and required size of ditches. The constructing commission has, however, been able to do the work about 40 per cent. cheaper than the estimated cost. The estimates allowed 15 cents per cubic yard for all earth work, while, for the greater part of the work, the commission has paid but 8 cents per cubic yard. This would make the completed system of main drains cost about 75 cents an acre, to the land directly benefited.

The difficulties to be overcome in treating an area, so flat and of such vast extent as the Red river valley, are not few and would tax the resources of the most experienced engineer. First, an accurate system of levels must be extended over the whole area involved. This may mean the actual territory to be drained—not only that land whose storm water flows across it, but also the land through which the ditches must be continued to reach an ultimate outlet.

Over 3,000 miles of levels were run to secure this information relating to about one hundred townships in the valley.

With these data at hand, a contour map was made, a study of which showed the area to be best treated in about 25 sub-drainage districts, varying in size from 15,000 to 65,000 acres. This provided for ditches of various lengths, size and carrying capacity to suit each local demand.

Ditch No. 10, in Norman County, was to be two and one-half miles long and was to cost $1,400 per mile. Ditch No. 20, in Clay County, three miles long, somewhat larger, would cost

$2,000 per mile. Sand Hill River ditch, in Polk County, would be 10 miles long and would cost over $8,000 per mile.

Up to date, about one hundred and twenty-five miles of ditch have been dug, costing about a quarter of a million dollars. The Great Northern Railroad contributed $25,000 of this, the remainder was raised by state appropriation.

From observations made last June by the writer it was learned that one of these average ditches at flood-tide passes 320,000 gallons per minute. At this rate the water coming to a square mile during an ordinary all-day rain will be carried away by the ditch in less than an hour.

ADA DITCH.

These ditches are the joint property of the state and the counties in which they are located and must be kept in repair by the county. To provide a mild supervision and to look after small repair, the need of which soon became evident, the last legislature created the State Drainage Commission and charged it with this responsibility.

Since strong local interest at every point urged its claims the commission has been guided in the difficult question decid-

ing what ditches to construct first, by the single desire to bring relief, as speedily as possible, to the greatest number, and at a minimum final cost. This policy strictly adhered to has resulted in the completion of that part of the work included in the first class above, that class for which nature had done most to secure a partial drainage. The work contemplated in the second division is about completed and work on the third class, which includes those lands provided with no natural means of drainage, is well begun.

The scheme of the complete drainage of the valley, contemplates that the side-ditches to all highways shall be so constructed that they shall become connecting drains to these main ditches. The counties have already done much effective work in this direction and there are now in the valley hundreds of miles of splendid turn-pike road, skirted on either side with deep, continuous ditches which would excite the wonder of a Southern Minnesota man and delight the heart of anyone whether he desired to go by land or by water.

The ultimate success of the undertaking has been assured from the time of the completion of the first ditch. With rare exceptions, owners of the land along the line of the ditch have aided by giving the right of way and in many ways assisting the commission. As in all enterprises of a public nature, the obstructionist was at first met. He sought to conceal his desire to sell to the state a few acres of land for double its market value, under the pretense that it would bring water to his land instead of freeing it of its own storm water. The construction of needed ditches has thus been prevented, or much delayed, by such greed-called narrow-mindedness, or undue caution by the more charitably inclined. Now that the benefits are unquestioned and the policy of the commission well known, such hindrances are no longer met.

To further assist the counties in carrying out the part originally assigned to them, of constructing the intercepting drains, an act was passed by the legislature of 1887 "to provide for the formation and organization of drainage districts for the drainage of wet and overflowed lands for agricultural and sanitary purposes."

The law was patterned after an Illinois law, and has proven

a wise measure. There are several counties in the Red river valley now working under its provisions. In the nine counties now interested in this work there will doubtless be hundreds of miles of secondary ditches dug during the coming summer. Some are even pushing the work of constructing a number of the main ditches, planned by the state, rather than wait for the state, whose funds for this purpose are about exhausted. Polk county has expended over $30,000 in this line of work during the past season.

With few exceptions, an inclination of two and one-half to five feet per mile could be secured for these ditches without the sacrifice of an economical section. These slopes give velocities of from one to two and one-third miles per hour, varying with the condition of the banks and the depth and sectional area of the ditch. With a velocity greater than three miles per hour, excessive erosion will take place in this loose clay subsoil. The lower half-mile of the Morken ditch, in Clay county, and portions of the Spring Creek and Ada ditches, in Norman county, are showing this tendency, and to prevent encroachment upon adjoining land and the roadway built upon the waste bank, it has been necessary to protect the slopes.

With a slope less than two feet per mile, a still worse evil develops. The lower four miles of the Rabbit river ditch, in Wilkin county, have a slope of about one and one-half feet per mile. This does not create sufficient current to prevent an accumulation of debris coming to the ditch from the cultivated fields and a gradual filling up of the channel takes place. If the ditch is without water except at flood season, vegetation soon gets a foothold and then the usefulness of the ditch is at an end. The Mustinka ditch, in Traverse county, is well advanced in this stage, and, until repaired, will furnish little relief in time of flood.

With these few exceptions the ditches are enlarging gradually as it was planned they should, are fulfilling all expectations of the projectors and are contributing their full share to increasing the wheat area and general productiveness of the already famous Red river valley.

SKETCH OF THE GEOLOGY OF THE EASTERN END OF THE MESABI IRON RANGE IN MINNESOTA.*

BY U. S. GRANT.

CONTENTS.

	PAGE.
Introduction	49
Physical Features	50
Outline of Geological History	52
The Pre-Animikie	53
The Greenstone	54
The Granite	55
The Animikie	55
The iron-bearing member	57
The Iron ore	59
Exploitation	60
The black slate member	60
The graywacke slate member	60
The Diabase Sills	61
The Gabbro	61

INTRODUCTION.

On the west the rocks of the Mesabi iron range first appear at Pokegama Falls on the Mississippi river in Itasca county. From this point they extend in a general east-northeasterly direction through the southeastern part of Itasca county and the central part of St. Louis county. Throughout this distance, nearly one hundred miles, the Mesabi rocks lie on the southern slope of a range of granite hills, known as the Giants range, and toward the east they are immediately overlain by a mass of later igneous rock,—the great gabbro mass of northeastern Minnesota. This gabbro gradually encroaches upon the lower and the lower parts of the Mesabi rocks until the latter are completely covered, and the gabbro lies directly upon the granite; this occurs on Birch lake on the eastern border of St. Louis county. From here eastward through Lake county the Mesabi rocks appear only in a few areas of limited extent at or

*The information here presented was obtained largely by the writer in the summers of 1892 and 1893, while working under the direction of the State Geologist, Prof. N. H. Winchell, for the Geological and Natural History Survey of Minnesota.

near the northern edge of the gabbro. But in Cook county, near its western edge, they again emerge from beneath the gabbro mass and extend eastward as far as Port Arthur and the east side of Thunder bay on the north shore of lake Superior.

The Mesabi iron-bearing rocks occupy a belt some eighteen miles in length in Cook county and then pass into Canadian territory at North lake. It is with this portion of the Mesabi iron range,—i.e., that lying in the northwestern part of Cook county,—that this paper deals. The district described is shown on the accompanying map which includes T. 65 N., Rs. 3 and 4 W., parts of Rs. 2 and 5 W., and some adjacent portions of Ontario.

PHYSICAL FEATURES.

The land was originally densely timbered with pine, spruce, balsam fir and birch, and in some places good groves of white and Norway pine still exist. Considerable areas have been devastated by forest fires and such areas are now covered by a dense second growth of poplar and birch. The soil is usually not thick, and the bare, glaciated, underlying rock frequently appears at the surface. The subsoil, where such exists, consists of glacial deposits which are commonly not more than a few feet in thickness. While the general appearance of the district would impress a farmer very unfavorably, still the dense timber evinces a fertile soil and it can be said that districts less attractive from an agricultural point of view are cultivated successfully in the eastern states.

The surface in general is broken and rough, though by no means mountainous. Steep hills rising one hundred or more feet above the surrounding country are common and usually have an east and west direction. The most marked elevation is a hill range of greenstone and granite which runs through the center of T. 65 N., R. 4 W. This is part of the Giants range and in one place (north side of Sec. 28, T. 65 N., R. 4 W.) it rises to 2,038 feet above sea level,—the highest point in the area here described,—while altitudes of 1,800 feet are common. The lowest part of the district is Sea Gull lake which is 1,440 feet above the sea. Thus the extremes of altitude differ by practically 600 feet.

ELEVATIONS IN FEET ABOVE SEA LEVEL.

South Lake	1,558
North Lake	1,550
Lake Emma	1,850*
Iron Lake	1,853
Gunflint Lake	1,547
Magnetic Lake	1,547
Loon Lake	1,745
Ham Lake	1,706
Bear Lake	1,748
Charley Lake	1,763
Akeley Lake	1,779
N. ¼ post Sec. 28, T. 65 N., R. 4 W.	2,038
Pine Lake	1,465*
Sea Gull Lake	1,440*

In the eastern half of the area shown on the map is a peculiar type of topography, which is characteristic of much of the northern part of Cook county and adjoining parts of Ontario. This type of topography, which in this region is confined to the area underlain by Animikie (or Mesabi) rocks, consists of long, parallel, monoclinal ridges running approximately east and west, with sharp mural escarpments on the north sides of the ridges and on the south, gentle slopes. Between the ridges and running parallel with them are long, narrow lakes. A general section, from north to south, through these ridges, is as follows: First, a long lake, and on the south side of the lake a steep talus slope, above which is a cliff, composed of slates dipping southward at an angle of about ten degrees. The top of the cliff is made by a sill of diabase, which has been intruded between the beds of slate. Beyond the top of the cliff the land generally rises for a short distance, until coming almost to the top of the diabase sill. Then begins a long, gentle, southward slope about on the upper surface of the sill. This slope, however, does not extend far enough to bring the land down to the level of the northern foot of the ridge, but beyond the gentle slope is another lake, considerably higher than the first, and on the south of this lake the talus, the cliff and the gentle southward slope are repeated. (Compare section EF on the accompanying map.)

*From aneroid readings; all others from levels.

As an example of how the general land surface and lake levels rise toward the south, we may cite Gunflint lake, which is 1,547 feet above the sea level, while less than a mile to the south is Loon lake, with an altitude nearly 200 feet greater.

The abundant lakes, elongated in an east and west direction, as well as the numerous northward facing escarpments, suggest at once the probability of a series of comparatively recent east and west faults along the north sides of which the downthrow has occurred. But a rather careful examination of the rocky structure of the district has brought forward no confirmatory evidence along this line; in fact it has produced evidence which is directly opposed to the existence of any considerable east and west faults. It seems that the present configuration of the surface could have been brought about by pre-glacial erosion acting on gently inclined strata of different degrees of resistance, the thin bedded and fissile slates being much more susceptible to disintegration and erosion than the diabase sills.

The district here described lies in two great continental drainage basins, that of the Hudson bay and that of the Gulf of St. Lawrence. On the International boundary line the divide between these two systems of drainage is the portage between South and North lakes. The former lake is 1,558 feet above sea level and the latter 1,550 feet, and on the portage a height of 1,600 feet is not attained. The waters of South lake and of some of the small lakes in the extreme southeastern part of the area flow eastward through the Arrow and Pigeon rivers into lake Superior, while North lake and all the rest of the district drains westward and northward to Saganaga lake, which lies in the northwest corner of Cook county just north of the lake called Sea Gull lake on the accompanying map. From Saganaga lake the waters flow westward along the north side of Hunters' "Island" and finally into Hudson bay.

OUTLINE OF GEOLOGICAL HISTORY.

In this area the rocks are easily separated, both on lithological and on structural grounds, into three divisions, the chief one of which is the Animikie series, containing the iron-bearing rocks of the Mesabi range. Older than these are the

Pre-Animikie rocks, while younger than the Animikie are some diabase sills and the great gabbro mass.*

The Pre-Animikie consists of granites, greenstones, both massive and schistose, conglomerates, slates and other clastic rocks. These were deposited, complexly folded, elevated above the sea level, profoundly eroded and sunk again below the sea level before the time of the Animikie rocks, which are found resting unconformably upon the upturned and eroded edges of the older Pre-Animikie. Some time after the deposition of the Animikie strata they were intruded by igneous matter which formed large sheets or sills of diabase between the different strata. Also later than the Animikie came the gabbro, a great mass of igneous rock which usually overlies the Animikie, although in some places it is intrusive into the earlier strata. In general, these three divisions of rocks occupy east and west belts, the Pre-Animikie being confined to the northern part of the district, the Animikie to the central, and the gabbro to the southern. Thus in traveling from north to south, one passes over newer and newer rocks.

There are no rocks in this area later than the igneous rocks mentioned above, except some small dikes of uncertain, though probably Keweenawan, age. The whole district has been glaciated and striated surfaces and roches moutonnees are abundant; in fact, all the disintegrated rock was removed by glacial action. The general direction of the last ice movement, as shown by glacial striæ, was almost exactly south. Comparatively little is known concerning the deposits of drift in this district.

THE PRE-ANIMIKIE.

The rocks included in this division can be readily separated into two parts, the greenstone and the granite. Associated with these are other rocks in part of clastic origin, such as conglomerates, slates, graywackes and schists of various kinds. These latter and the greenstone have all been included under one term and called Keewatin, but as the greenstone is the only one of these Keewatin rocks which is intimately associated

*The Pre-Animikie rocks here described, according to the nomenclature used by the United States Geological Survey, belong to the Lower Huronian series of the Algonkian system and probably also in part to the older Archean or Basement Complex; the Animikie is regarded as the equivalent of the Upper Huronian series of the Algonkian, and the gabbro as the lower part of the Keweenawan series of the Algonkian.

with the Mesabi iron-bearing rocks in this area it need be the only one to be here described. However, on the Canadian side of Gunflint lake other rocks of the Keewatin appear.

The Greenstone.

Lying just to the north of the iron-bearing Mesabi (Animikie) rocks in T. 65 N., R. 5 W., and extending eastward to the center of T. 65 N., R. 4 W., where it disappears under the Animikie strata, is a belt, averaging about two miles in width, of rocks which have been called greenstones because of their general dark greenish color. They are crystalline rocks composed essentially of a ferro-magnesian mineral, which is almost always green hornblende, and plagioclase feldspar. These rocks vary exceedingly, even within short distances, at one place being quite coarse grained and granitic in texture and in another place being quite fine grained. The hornblende varies much in amount and frequently makes up almost the entire rock. In general, these rocks are at present diorites. At places, especially along the east side of Sec. 27, T. 65 N., R. 5 W., the greenstones contain angular and sub-angular fragments of rock almost like themselves, but nothing like a true conglomerate has been found in the area designated as greenstone. Nor is there any positive evidence of any sedimentary rock within the greenstone area in Minnesota shown on the accompanying map.

While the original nature of all the rocks here called greenstone cannot be stated positively, it is certain that they are essentially igneous in origin, although some parts may be regarded as composed of fragmental volcanic rocks. In lithological character some of these greenstones were certainly diabases and others were of the nature of andesites, while a large part seem to have been diorites or possibly gabbros. They have been subjected to much alternation and recrystallization, and it seems likely that parts of them have been altered more than once since their original formation.

Associated with the greenstones, especially in Secs. 22, 23 and 24, T. 65 N., R. 5 W., are some small masses of more acid rocks,—quartz porphyries and quartzless porphyries,—all of which are probably younger than the greenstones. While the evidence for each small mass is not complete, the following facts point to the truth of the above statement as to the age of

these more acid rocks: (1) They sometimes occur in the form of small dikes in the greenstones. (2) When in larger masses they sometimes show a finer grain at the contact lines with the greenstones than at some distance from these lines. (3) They have not acquired the schistose structure which is frequently, though by no means universally, developed in the greenstones. It can be stated that the greenstones as a rule are massive and cannot be called "greenstone schists" except locally.

The Granite.

The northern part of this area is covered by a mass of granite which, on account of its extensive and typical development on the shores of Saganaga lake (just north of Sea Gull lake), has been called the Saganaga granite. This rock is a coarse grained hornblende granite. The coarse grain, uniform character and large quartz grains, sometimes half an inch across, are characteristic features of this granite mass.

Along the southern border of the granite, as it approaches and is in contact with the greenstone, the grain becomes finer than usual and the quartz in places almost entirely disappears. Along this edge of the granite mass its relation to the greenstone can be distinctly seen in many places. At one locality (less than one-fourth mile south of the N. E. corner Sec. 23, T. 65 N., R. 5 W.) many granite dikes, from one to twenty-five feet in width, are seen cutting the greenstone. At another place (south shore of West Sea Gull lake) is a bold bluff of greenstone cut in every direction by branching vein-like forms of granite of the same nature as the immediately adjoining main mass of Saganaga granite. And the greenstone and these granite dikes themselves are also cut by another series of finer grained and more acid granite (aplite) dikes.

THE ANIMIKIE.

The Animikie rocks are the rocks of the Mesabi iron range and as such are of importance both economically and geologically. As developed in the district under consideration they are the equivalents, both in age and origin, of the rocks of the

productive portion of the Mesabi iron range to the west in St. Louis county.*

Throughout the extent of the Mesabi range the Animikie rocks, dipping usually at a small angle to the south, rest comfortably upon the older Pre-Animikie rocks, and usually upon the southern slope of the Giants range of hills which is composed essentially of granite. The strike is approximately east-northeast, with some local exceptions. In the district here considered the surface outcrop of the Animikie, as shown on the accompanying map, varies from nothing to something over three miles, and the thickness from nothing to nearly 4,000 feet, while the dip is in general about ten degrees a little east of south.

The rocks of the Mesabi range are readily separable on lithological and stratigraphical grounds into four comformable divisions or members which are as follows, beginning with the lowest or oldest: (1) The lower, or quartzite member, called the Pewabic quartzite; (2) the iron-bearing or taconyte member; (3) the black slate member; (4) the graywacke slate member. The quartzite member is well developed in Itasca county, but gradually becomes thiner and thiner in surface outcrop towards the east and before reaching the eastern side of St. Louis county has entirely disappeared; nor does it reappear in Cook county.

An estimate of the maximum thickness, in feet, of the different members as exposed in that part of Cook county here described is as follows, the estimate being based on the assumption that there are no east and west faults which would make the apparent thickness greater than the real:

	Sediments.	Diabase.	Totals.
Graywacke slate member	1,650	250	1,900
Black slate member	950	100	1,050
Iron-bearing member	825	75	900
	3,425	425	3,850

*For an account of the geology and ore deposits of the productive portion of the Mesabi range see:

H. V. Winchell: Geol. and Nat. Hist. Survey of Minn., 20th Ann. Rept., pp. 111 180, 1893.

J. E. Spurr: Ibid., Bull. 10, 1894.

The Iron-bearing Member.

Towards the western edge of Cook county this member first appears, between the greenstone on the north and the gabbro on the south, near the center of the west half of Sec. 34, T. 65 N., R. 5 W. (See map.) It extends eastward, holding the same position with respect to the adjoining rocks, as a narrow belt for about six miles when it rapidly widens and soon attains a width of over a mile. At the western end of Gunflint lake the iron-bearing rocks leave Minnesota territory, but reappear on the broad point between Gunflint and North lakes. They outcrop in many places at and near the north shore of Gunflint lake and evidently underlie much of the northern half of this lake. To the east of the west end of North lake the iron-bearing member is not known in Minnesota, but it extends eastward in Ontario as far as Port Arthur on Thunder bay, north shore of lake Superior.

The dip of the iron-bearing member west of the center of Sec. 27, T. 65 N., R. 4 W., and south of the greenstone is toward the south, varying from twenty degrees to almost vertical, and the width of the outcrop is from 300 to 1,300 feet. The average dip is from forty-five to fifty degrees. Where this belt of rock is the widest the dip is about thirty degrees. This would indicate a thickness of 650 feet, which is probably the maximum thickness of these rocks west of the center of Sec. 27. To the east of this the dip is much less, averaging less than fifteen degrees, and the outcrop is much wider, being a mile and a quarter in width along the west side of Secs. 23 and 24, T. 65 N., R. 4 W. The thickness of the iron-bearing member also increases towards the east and reaches about 900 feet, of which 75 feet is diabase.

West of Sec. 27 the iron-bearing rocks lie low down on the southern slope of a prominent greenstone ridge which decreases in height in the northern part of this section until it disappears completely under the Animikie strata. These Animikie strata swing around to the north and pass from the greenstone onto the granite. A narrow belt of the iron-bearing rocks extends westward nearly to the western side of Sec. 21, T. 65 N., R. 4 W., being flanked both on the north and south by greenstone. The structure of this belt is synclinal and the Animikie rocks

evidently once extended, in the form of an anticline, over the high greenstone ridge, which now separates the two belts of the iron-bearing member. (See map, section CD.)

In general characters the rocks of the iron-bearing member in the district here described are quite similar to the rocks of the Mesabi iron range in St. Louis county. They differ, however, in two features,—first, they frequently are more completely crystallized than the same rocks of the western Mesabi, and second, the iron, instead of being in the form of hematite, is almost entirely magnetite. It will not be necessary to describe the lithological characters of the rocks of the iron-bearing member except to state that they consist chiefly of jaspers, amphibole (grünerite) schists, greenish siliceous slates, cherts, cherty carbonates and magnetite slates. They may all be conveniently included under the term taconyte*, which is a name commonly applied to the rocks of the iron-bearing member of the Mesabi range. These rocks are regarded as originally glauconitic green-sands, and the ore has been derived from the iron in the glauconite, the ore bodies being due to concentration and replacement†.

The narrow belt of iron-bearing rocks, lying west of the center of Sec. 27, T. 65 N., R. 4 W., differs from the rest of the rocks of the iron-bearing member in being highly crystallized. They consist of rather coarse-grained aggregates of the following minerals: quartz, magnetite, olivine, hornblende and augite. The marked banding which is characteristic of the taconyte rocks is still preserved in this crystallized portion of these strata which are made up of bands, varying in width from a fraction of an inch to a foot or more; composed of any one of the above minerals or of mixtures of them. The magnetite and quartz frequently form bands by themselves. The coarse crystallization of this portion of the iron-bearing strata is due to the effect of the gabbro upon the rocks with which it came in contact. All along the northern edge of the gabbro mass it has re-crystallized the older sedimentaries, and this effect can nowhere be better seen than in this belt of iron-bearing rocks, west of the center of Sec. 27. At the southwestern corner of

*H. V. Winchell: Op. cit., p. 124. †J. E. Spurr: Op. cit., pp. 248-249.
‖J. E. Spurr: Op. cit.

Loon lake the recrystallizing effect of the gabbro on the graywacke slate member of the Animikie is also very apparent.

The Iron Ore. This consists almost entirely of magnetite, although a little hematite has been reported from near Gunflint lake, both on the Minnesota and Ontario sides of the boundary. The magnetite occurs disseminated through the rocks of the iron-bearing member, and it is also concentrated into numerous bands. Over large areas thirty to forty and even fifty per cent of the rock is magnetite. Towards the base of the formation the iron ore is more abundant and here are frequently found beds of almost pure magnetite. These beds vary in thickness from a few inches to three or four feet. The ore occurs in bands or beds and not in irregular or lens-shaped bodies as on the western portion of the Mesabi range. This, as well as the absence of very large concentrations of ore, is probably due to the fact that time enough had not elapsed, between the deposition of the Animikie rocks and the intrusion of the gabbro and of the diabase sills, to allow of the formation of large bodies of ore. The advent of the igneous rocks more or less crystallized the sedimentaries and changed the iron ore to magnetite,—in short reduced the rocks to such a condition that they did not present suitable conditions for the alteration of the ore and its concentration by circulating waters, while on the western Mesabi the formation of ore bodies has been able to go on even to the present day.

In the district here described no ore bodies have yet been found which are at the same time both rich enough and large enough for profitable mining at the present prices of iron ore. There are, however, vast quantities of this magnetite ore at and near the surface, and there seems to be no reason why it could not be profitably mined were the prices of ore a little higher than at present.

The following partial analyses show the general composition of the iron ore of this district:

	I.	II.	III.	IV.	V.
Metallic iron, Fe	58.40	54.01	63.98	62.05	55.60
Manganese, Mn	4.92	5.02	none	.....	4.34
Silica, SiO_2	8.22	9.37	8.90	7 14	10.02
Alumina, Al_2O_3	.52	.07	.....	.....	.34
Phosphorous, P	.036	.032	.028	.113	.042
Titanium, Ti	none	none	trace	.....	none

Exploitation. In 1886 and 1887 considerable exploratory work and some test pitting was done in the iron-bearing rocks at various localities west of Gunflint lake. A diamond drill was brought by wagon and canoe from Grand Marais on Lake Superior, and several drill holes were put down in Secs. 28 and 29, T. 65 N., R. 4 W. The rocks pierced in one place by this drill were reported as follows: siliceous rock, 30 feet; clean ore, 15 feet; mixed ore, 17 feet; clean ore, 10 feet; greenstone, 12 feet. The "clean ore" evidently was not pure magnetite, but was probably rock of nearly uniform composition consisting largely of magnetite. The results of the exploration and drilling led to the organization of the Gunflint Lake Iron Company, which began active operations in Secs. 28 and 29 in the spring of 1892. In the following winter the Port Arthur, Duluth and Western Railroad was completed to the company's headquarters in Sec. 28. Five miles of this railroad are in Minnesota territory. On the advent of the railroad machinery was obtained and a working shaft, eight by twelve feet in size, was sunk in the S. E. ¼ N. E. ¼ Sec. 28. This shaft reached a depth of 105 feet. A smaller shaft, on the north shore of Akeley lake in Sec. 29, was sunk to a depth of about 75 feet. No ore was shipped and the workings were abandoned in the fall of 1893.

The Black Slate Member.

This consists essentially of fine grained, black, more or less siliceous, apparently carbonaceous slates which are frequently quite fissile, although in a few exposures they are remarkably massive and might be easily mistaken in the field for fine grained, black, igneous rocks. In thin section typical specimens of these black slates are seen to be composed of numerous small, angular fragments of quartz in a cement of dark color and apparently carbonaceous character.

The Graywacke Slate Member.

This is composed of black to gray slates and fine graywackes, with some flinty slates and the upper part shows coarser detrital matter, while the highest beds seen in this area are fine grained quartzites and quartz slates. The strata of this member are well exposed along the south shore of Loon lake and especially along the north side of the long point on the

south side of the lake. Towards the west end of the lake some fine grained quartzites occur.

THE DIABASE SILLS.

Associated with all members of the Animikie are extensive sheets of diabase which have been intruded between the Animikie strata and which are now exposed over considerable areas. Indeed the hard resistant nature of these diabase sills renders them much more conspicuous than their actual number and thickness, as compared with the associated sediments, would warrant. All of the igneous rock associated with the Animikie in Minnesota is, as far as known, intrusive in its nature, and in the Animikie time there was no surface igneous activity. Thus it was an epoch of quiet and continuous sedimentation sharply in contrast with both the older Keewatin and the newer Keweenawan, both of which were times of widespread volcanic activity.

The diabase sills vary in thickness from a few feet to about 100 feet, or even more. The thickest one in the area here described is that shown on the map as extending along the north side of Loon lake. These sills, especially the larger ones, are quite coarse grained except near their upper and lower sides, where they become very fine grained and in places almost glassy. The adjoining Animikie rocks are altered for only a few feet from the contact of even the largest sills.

THE GABBRO.

Bounding the Animikie rocks on the south is the great gabbro mass of northeastern Minnesota. This gabbro is an igneous rock of later date than the Animikie. It is composed essentially of plagioclase feldspar (usually near labradiorite) and augite, with some olivine and magnetite. At and near the contact of this igneous rock with the Pre-Animikie and with the Animikie sediments, it has produced a marked metamorphism and usually a complete recrystallization, as has been mentioned under the description of the iron-bearing member of the Animikie.

The gabbro is usually of uniform grain and composition, but varies sometimes in two distinct directions. In one the feldspar increases and the other minerals decrease in quantity

until a nearly pure plagioclase rock results, and in the other direction the magnetite, which is titaniferous, increases in amount until it forms all or nearly all the mass of the rock. Variation in this latter direction produces deposits of titaniferous magnetite which are not uncommon, and which sometimes reach considerable size. These deposits of titaniferous magnetite are not at present worked. Large amounts, however, of this ore exist and will be of value when they can be reduced as cheaply as non-titaniferous ores. Such deposits occur on Mayhew and Iron lakes, at the southeast corner of T. 65 N., R. 3 W. Analyses of the ore from this locality are as follows:

	I.	II.
Silica, SiO_2	2.02	20.90
Alumina, Al_2O_3	2.68	1.75
Titanium binoxide, TiO_2	12.09	2.23
Magnetic oxide of iron, Fe_3O_4	80.78	72.30
Chromium sesquioxide, Cr_2O_3	2.40	.....
Magnesia, MgO	.....	2.63
Lime, CaO	trace	trace
Phosphorus, P	.03	none
	100.00	99.81
Metallic iron	58.48	52.46

Lately some excitement has been caused by the reported discovery of large percentages of nickel in the titaniferous magnetites of the gabbro in Cook county. Nickel does occur in similar situations and is frequently found as an impurity in one of the gabbro minerals (olivine), but as yet no reliable reports of nickel ore rich enough for mining have been received. A determination of the nickel in iron ore from the locality of the specimens above analyzed showed less than one-half of one per cent.

SHOP WORK FOR ENGINEERING STUDENTS.

BY J. H. GILL.

In this article it will be taken for granted that a course in practical shop work is advisable for students in mechanical and electrical engineering. The objects aimed at should be not to make expert blacksmiths, machinists or pattern makers, but to give the students a practical working knowledge of the principles and methods involved in engineering construction. To do this a certain amount of preliminary work is necessary to give those who have had no previous shop experience familiarity with tools and machines. This is best done by exercises carefully planned to give the necessary training in the shortest time possible. Then leave the pure exercise work and give the student the construction of some machine or piece of apparatus.

Begin with the exercise work and make it a step in advance for a student to pass from the pure exercises to the construction work. No student will take the interest in an exercise which goes into the scrap heap that he will in a piece of work which is to be used after he is through with it. In all the work, use, as far as possible, the methods which would be followed by the commercial shop on work of the same kind.

The modern shop methods are very different from those in use ten or even five years ago. For an example take the methods of manufacture of the bicycle hub. It is not many years since a hub of the style used at present would, if made from the solid bar or forging, be bored and then turned on an ordinary mandrel in an engine lathe with the common forged lathe tools. Now watch the modern hub machine turn one from the solid bar with formed cutters while the oil tube twist drill bores the inside. Another example is the automatic screw machine turning out duplicate work with what seems almost human intelligence. These are only examples, but they show the tendency of the times toward special machines and tools. Of course it is impossible to illustrate in the school shops all the labor saving machines and tools found in the shops of today, each having the machines best adapted to its own class of work.

Much can be gained by inspection trips to the shops that are accessible. Another great help would be a course of lectures on shop management and methods illustrated by a series of lantern slides showing the tools and methods used by the most successful manufacturers in different lines of work, and if possible in different parts of this country and Europe. This would be especially valuable to us of the Northwest, as it is impossible for us to have access to the large manufacturing and contract shops of the East. A course of lectures on steam engine construction, for instance, with slides illustrating the methods of E. P. Allis & Co., of Milwaukee; locomotive work with slides from the Baldwin Locomotive Works; or dynamo and motor work as done by the General Electric Company, would give the student an insight into methods and designs which would be of much value to him in his after work. If the collection of slides is kept up they would, in a few years, form a most valuable help in machine design and construction.

In place of quite so much practice in plain machine work if we could, after the principles of the different machines are mastered, take up more of the modern methods of doing work, it would give an idea of the advantage of special tools, jigs and gauges. Have a turret lathe or screw machine and introduce some duplicate work. Then devote the last term to the manufacture of some machine. If possible, build several of the same kind.

Special tools, jigs and templates should be used for the work where advantageous. Use manufacturing methods and crowd the work as much as may be consistent with accuracy and good work. For instance, when several pullies are to be turned select the lathe best suited to the work, also have tools, gauges, etc., ready and then rush the whole lot through with only once getting ready for the job. Keep a system of time checks on all work and maintain the standard of accuracy. Encourage the students to design tools, attachments and methods for turning out accurate work in the least time possible. In every way try to cut the time and cost of the work of this last term as much as possible and keep the standard of quality high.

In this way the student will overcome, in a measure, the feel-

ing that all that is necessary is to put in the specified time, the amount of work being a secondary consideration, and catch the spirit of the modern manufacturer which is developed by contact with competitive commercial work. The instructor must keep up with the times in all branches of the work which are covered. It would be advisable to spend every alternate summer vacation, at least, in some one of the larger and most successful shops studying their designs and methods.

With the shop work developed along the lines indicated and a course of lectures covering points and classes of work which cannot be illustrated in the shops of the school the writer believes the course in shop work can be made of greater benefit to engineering students than is usual.

BRIDGE ERECTION.

FRANK H. CONSTANT.

If, strolling along the shore of a river, one passes the spot at which a bridge is in process of erection, he will notice, in addition to a bewildering confusion of scaffolding, derricks and kindred erection appliances, many tons of steel columns, bars and beams scattered promiscuously over the ground, or piled up in great, disordered heaps. This shapeless mass of steel is the future bridge which needs but to be framed together in proper order, over the river, to form a highway for fast moving trains or a diversified city traffic. Upon this steel many hours of labor have been expended in shops located at great distances from its present position. Yet, all of this labor would be in vain were this material not to pass through the final stage in its evolution—the erection. Hence, the erection of bridges has become a necessary field of study for the structural engineer.

Since a bridge is to span a gap, special means must be adopted to support it during erection. Since this gap may be the distance between the shores of a swiftly flowing river, or the sides of a deep ravine, and as the structure is always large, cumbersome and heavy, the erection of a bridge, even under favorable circumstances, requires thought, skill and experience. But add to these inevitable difficulties the liability of floods, washouts, treacherous foundations under timberwork, heavy winds, accidents from innumerable causes, the problem frequently requires genius and courage of a high order for its solution. Indeed, where these dangers are greatly to be feared, it is necessary to adopt some special form of construction, such as the cantilever, suspension or arch bridge, which, while frequently uneconomical in cost of material, may nevertheless be erected with the minimum possibility of accident. These bridges may be advantageously used over treacherous rivers or deep valleys, and may be built out from the shore without the use of temporary intermediate support.

Such construction gives rise to an unusual distribution of stresses during erection, necessitating the use of excess material.

Whatever the mode of erection, field connections are always to be made, often in awkward places and at perilous heights. It is therefore necessary to plan for erection at the time when the outline of the structure itself is first conceived, and during every step of the design the needs of the erector should be kept in mind that the parts may come together without unnecessary difficulty.

An important bridge is expeditiously erected only with the assistance of many appliances, such as tools, derricks, engines, winding drums, falsework, trusses, travelers. So expensive is such an equipment, that the erection of important structures is contracted to erection firms who, with a capital frequently of several hundred thousand dollars, have yards and shops of their own, employ skilled and college bred engineers to plan and superintend their work, and assume all risk to the structure during erection. The sudden collapse of some half erected bridge, with its burden of human lives, only too often demonstrates that this risk is not imaginary. The erector generally plans his own mode of erection, (subject to the approval of the engineer), and furnishes all appliances not actually a permanent part of the structure.

The mode of erection to be adopted in a particular case will vary with the kind of bridge and the nature of the local conditions. In the following paragraphs some of the most common methods will be briefly discussed.

GIRDERS.

The simplest form of bridge is a beam or girder. If it is to replace an old bridge, the car containing the girder will be drawn to the center of the old structure and the girder will be lowered to the abutments parallel to the track. The car is withdrawn, and during an interval between trains the old structure is demolished and the new girders skidded to their final position. If there is no old structure, the girder may be rolled from one abutment upon a wooden beam temporarily thrown across the opening; or a wooden trestle bent may be erected midway between the abutments to support the end of the girder as it is pushed across the opening. If the girder is long; several bents will be employed; or a temporary track will be laid across upon which the car containing the girder may pass.

Sometimes the intermediate bent is omitted and a pilot beam is lashed to the front end of the girder, of such length as to reach to the farther abutment before the center of gravity of the girder passes the first abutment.

SIMPLE TRUSSES.

The majority of bridges are of this type, and are generally erected upon falsework composed of timber trestle bents, whose sills rest upon the bed of the river, and whose caps are in the plane of one of the chords of the bridge. When the bed of the river is soft or subject to scour, the sills of the bents are supported upon transverse rows of piles driven to a firm resistance and cut off just above the surface of the water. The floor beams and lower chord of the bridge are laid directly upon the upper decking of the falsework. The upper part of the steel work is hoisted and placed into position by means of a timber framework called a traveler, which is composed of two or three transverse timber bents, braced together longitudinally at distances apart equal to the length of a panel of the bridge, and of sufficient width and height to completely enclose the new bridge. The traveler moves longitudinally upon rails placed on top of the falsework and outside of the trusses. The erection of the bridge begins at the center by the framing of the center posts, diagonal bars, top chord and lateral rods. When the center panel has been made self-supporting the traveler is moved to the next panel, which is raised in a similar manner. When one-half of the bridge is completed, the traveler is moved back to the center, and the erection of the other half proceeds in a similar manner. When the last member is in place and the last pin driven, the traveler is taken down, the blocking driven out from under the lower chord, and the bridge is said to be swung, viz., is self-supporting.

Sometimes, when floods are expected which would endanger the falsework, or when the channel of the river must be kept open to boats, the trestle timberwork is constructed in a quiet, shallow cove, often several miles from the site. Upon this falsework the bridge is erected in the ordinary manner. Barges, containing water in their holds, are moored between the bents of the trestlework, and upon their decks are constructed similar bents of sufficient height to reach to the lower chord of the

bridge. The series of parallel boats are braced together, and by pumping the water from them the bridge is lifted from the fixed trestlework and is supported entirely by the bents upon the boats. It is now floated to the bridge site and placed in position over the piers. When the water is again admitted to the barges, the bridge is gently lowered to its final position upon the piers.

When a new bridge is to be built upon the site of an old structure, the old bridge may be made to support the new one during erection. In this case the new structure must be designed with this end in view, so that the old may not obstruct the new. If the new bridge is a little wider and higher than the old, little difficulty will be encountered until the floor system is reached. At this point it will be necessary to remove the old bridge—at least in part. If the passage of trains is to be maintained, the old floor system should be removed only in sections and only so much at one time as can be replaced between trains. Thus gradually the old bridge is taken out of service and may finally be removed entirely. When an old span must carry both the traffic during erection, and the weight of the new structure, it should be strengthened by supporting it at intermediate points upon trestlework. Often the entire weight of the trains is carried upon the trestlework, and the new structure is erected and the old one removed simultaneously.

The maintenance of railway traffic is always a problem requiring ingenious and careful solution. Old and new parts can not occupy the same space, and withal, if the weight of trains, as well as of old and new spans, is to be carried by trestlework, the construction of the latter should be made with this end in view. During such erection a curious entanglement of wood, and old and new steel results.

Sometimes parts of old constructions are to be gradually replaced by new parts without disturbing the railway traffic. Falsework is generally needed in such cases to support the tracks, and, at times, the weight of the bridge. Notwithstanding the many chances for delay and obstruction due to the composite character of the work, the work is often prosecuted with great rapidity. During the reconstruction, in the manner here described, of three deck span bridges on the line of the Chicago

Northwestern, the writer remembers seeing, recently, forty or fifty feet of old floor beams, stringers and ties removed, and replaced by an entirely new system ready for the support of trains, during the two or three hours interval between trains.

VIADUCTS.

Viaducts consist of a series of steel towers connected by short spans. The towers are sometimes erected by means of four gin poles. These are vertical poles, guyed by wire ropes, with block and tackle attached to their top ends, with which the columns and bracing of the first story of the tower are hoisted into place. The four poles are then raised to the top of the completed portion of the tower and lashed to the four columns. The second story is then raised in a similar manner. The towers of the Kenzna viaduct, which are nearly three hundred feet high, were erected in this manner. After the towers are built the intermediate spans may be put together on the ground between two adjacent towers, and then finally hoisted into place. If the spans are too long for this, and (a condition which nearly always accompanies this) the towers too high for the economical use of falsework, cantilever construction may be efficaciously resorted to. If the spans are long, but the towers not high, a single intermediate bent or tower of wood may serve to allow the spans to be hoisted from the ground in two parts and finally connected in place.

But the most common method of erection of viaducts is by means of an overhanging traveler. This consists of a wooden framework supported upon wheeled trucks, from which horizontal timber beams project sixty to ninety feet. The projecting booms are held in place by guy ropes which pass over the top of the framework and are anchored near the rear end of the trucks. The weight of boilers, engines and hoisting drums, placed near the rear end of the traveler, balances the weight of the projecting arm when the traveler is being moved. When in position for work the rear end of the traveler is lashed to the floor of the bridge. If the traveler, when placed at the extreme edge of the completed part of the structure, reaches to the adjacent tower, this latter may be raised either in parts and framed together in place, or bodily (after framing bents upon the ground), by means of tackle from the traveler. The

intermediate girders may either be carried out upon the boom of the traveler and lowered into place, or raised from the ground. If the intermediate spans are long and the traveler only reaches to the nearest bent, it may be necessary to erect a derrick upon this bent, by means of which the second bent, which is first framed on the ground with its feet in position on the pedestals, may be hoisted to a vertical position by guy ropes attached to its top. The derrick is also of assistance in raising one end of the intermediate truss. If the intermediate span is longer than the overhanging boom of the traveler an intermediate wooden bent will have to be raised in a manner similar to the permanent tower. By means of this bent and a temporary wooden truss placed between the viaduct and this bent, the traveler may be advanced sufficiently far to enable the adjacent tower to be erected. The truss likewise may be raised in two pieces and connected in place. If the towers are high and the spans long, the towers may be erected by the gin-pole method and temporary wooden trusses may be hoisted into place across the opening, upon which the permanent span may be erected at leisure and without the uncertainty consequent upon attempting to raise complete and heavy spans from the ground.

ELEVATED RAILWAYS.

Elevated railways are generally erected by means of an overhanging traveler in the manner already described. Sometimes, when the streets are not crowded, the traveler is made to rest upon rails placed upon the ground outside of the steel structure. In this case, the traveler is made wide enough and high enough to completely enclose the viaduct.

CANTILEVERS.

If, for any reason, falsework cannot be used in erecting a long span bridge, or the method of floating the span into place is impracticable, cantilever erection must be resorted to. This does not necessarily mean that the structure will be a cantilever bridge when finished, since an arch or even a simple truss bridge may be erected as a cantilever. In either of these cases, however, some means must be adopted for anchoring the projecting structure to the shore or finished part of the bridge. As the methods of erection are alike in all of these cases, let us consider a pure cantilever bridge. This is generally composed of three

parts—a shore or anchor arm, a cantilever or river arm, and a simple suspended span joining the projecting ends of the two cantilever arms built from each pier.

Since the anchor arm is generally placed over shallow water or land, it must be erected upon falsework in the manner already described for a simple truss bridge. If it is a deck bridge the traveler is placed upon the upper deck and may be of any convenient width. If it is a through bridge the traveler is placed at a lower elevation, and must be narrow enough to move entirely inside of the trusses. But in either case, the traveler is constructed with an overhanging projection at the river end, having a reach of at least two panels of the bridge. The construction of the river arm begins at the anchorage pier and proceeds to the river pier. The traveler is now projecting over the open river. By means of this over-hanging arm the steel members of the first panel of the river arm, which are hoisted from boats below, or rolled out to the end of the bridge upon small cars, are framed into place. The traveler is now moved out upon this panel, and the second panel is erected in a similar manner. Except to place heavy wedges, or a toggle arrangement, in the upper and lower chords between the ends of the cantilever arm and the suspended span, this mode of construction is continued until the middle of the suspended span is reached. Rarely will the two parts, built out from the opposite shores, exactly meet at this point. A change in the temperature, or more or less play in the joints, may cause a deviation, even with the exercise of great care, of several inches. The value of the wedges or toggles is now apparent. They are operated by heavy screws, and by moving them one way or the other the ends of the bridge may be made to move in or out, up or down, at the will of the operator, until they are in such a position that the final central connection may be made. The wedges are now removed and the center span hangs freely from the ends of the cantilever arms by four vertical members. The horizontal members against which the wedges acted, while subjected to heavy stresses during erection, are not necessary after the central span is swung. They are retained, however, partly for the sake of appearance, and partly to prevent undue longitudinal vibration of the suspended span.

Cantilevers are nearly always uneconomical of material and are much less rigid than a simple span. This style of construction is only used because of ease in its erection. Sometimes a simple span may be erected as a cantilever, to effect which the two halves must be anchored back to the shore, or to spans already in place which can perform the function of anchor arms during erection. A toggle or wedge adjustment in the temporary member joining the anchor and river spans will allow the final connections to be made at the middle of the river span, after which the temporary member may be removed. By thus reducing both river and anchor spans to simple bridges, reversal of stresses during the passage of trains is avoided, and the metal may be more economically placed than in a pure cantilever bridge.

ARCHES.

Arches may be erected either upon falsework or as cantilevers. In the latter case they must be anchored to previous construction or to the shore, in the manner just described for a simple span. If there are several arches, contiguous spans may be built out simultaneously from the intermediate piers in such a manner that the two arms may balance each other. This was the method adopted in erecting the Ead's Bridge at St. Louis.

Mr. Waddell, in his new book, "De Pontibus," just published, suggests an ingenius method of erecting a three hinged arch. This consists in building each half of the bridge in a vertical position over its end pin, and then lowering the two halves by means of cables until they meet at the center. The economy of such a method will depend upon the available anchorage for the cables and upon the cost of scaffolding upon which the vertical leaves of the bridge may be erected. The most advantageous method in this, as in all cases, will depend upon local conditions.

SUSPENSION BRIDGES.

This is the only other type of construction than the cantilever which may be erected without falsework. As the suspension bridge is destined to become the type of the future bridges of the world, the method of its erection is a matter both of interest and importance. Although there can be little doubt but

that the mode of erecting this kind of bridge will undergo great improvement in the future, in this article we cannot do more than touch upon the method used in the past and present.

The suspension bridge consists of three essential parts, the cables with their hangers, the stiffening trusses which preserve the form of the cables, and the floor system. The construction of the cables is by far the most difficult part of the work, for these are composed of many thousand small parallel steel wires, each of which must be adjusted to its right length and moved to its proper place in the cable while swinging in mid air between towers possibly several thousand feet apart. Nay more, the cables must be thus built up, compacted, wrapped, and made capable of carrying the floor, before more than the smallest footbridge for the workmen to walk upon is possible at this dizzy height. It is like constructing upon nothing a very substantial something.

The erection of the Brooklyn bridge was begun by hauling three quarter-inch wire ropes across the river, hoisting them into sheaves placed on top of the towers, carrying the ends back to the anchorages, where they were spliced together and passed around sheaves. Thus, an endless rope, called a traveler, was formed, which was used for hauling other cables and supplies across the river. Several travelers were formed in a similar manner. Two larger cables, two and one-half inches in diameter, were next swung between the towers and the ends made fast to the anchorages. Strips of wood, four feet long and two inches apart, were clamped to these two cables, and with a five-eighths rope for a railing, formed an airy foot-bridge for workmen to walk upon. Other cables, two and one-half inches in diameter and spaced the width of the future bridge, were likewise swung from anchorage to anchorage and joined transversely, at intervals of one-fourth of the distance between towers, by narrow four-foot platforms, called cradles. From these cradles men could reach the newly made cables and adjust the wires to their proper length and position while they were being spun across the gap.

The cables of the Brooklyn bridge are composed of nineteen strands, each of which contains two hundred and seventy-eight wires. The strand formation is maintained simply for conven-

ience in erection and is completely destroyed in the finished cable. The strands are made by passing a continuous wire backward and forward, from anchorage to anchorage, the requisite number of times. This is accomplished by passing the wire around a sheave, which in turn is attached to, and moves with, one of the travelers. Men in small buggies wrap the completed strand at intervals of two or three feet with a few turns of small wire. When all of the strands have been brought into their final position in the cable, these wrappings are removed, one by one, and strong collars, made in halves to closely fit the cable, and compressed by long bolts, are placed around the cable at short intervals, and the many thousand wires composing the cable compressed into a round, compact whole. The cable thus formed is finally wrapped with a small wire, operated by a reel, which, with every turn, advances a distance along the cable equal to the thickness of the wire.

The vertical suspender ropes are next attached to the main cables, and, beginning at the towers, and laying a temporary floor as advance is made, the floor-beams are readily attached to the lower end of the hangers. Upon this floor the stiffening truss and other permanent parts of the bridge may be erected at leisure. In the manner thus outlined, it is quite possible to erect suspension bridges of several thousand feet span. Expert engineers have reported that a span of forty-three hundred feet between towers is practicable upon the present basis of construction. Doubtless improved methods would be discovered, which would greatly facilitate erection and increase, if it were desirable to do so, the maximum limit of span.

Like an ant moving loads many times larger than himself, so the erector brings into existence gigantic structures. Opposed at every step by the fiercest of Nature's forces, his failures are remarkably few, while his triumphs stand as monuments to his skill in every quarter of the globe.

A HIGH OR LOW TENSION ALTERNATOR.

H. F. M. DAHL.

One great advantage of a multipolar inductor alternator is the facility with which independent currents may simultaneously be derived from the stationary armature at either high or low potential for adjacent or distant consumption. Constant potential A. C. generators with rotating armature have only one working voltage. Any other is obtained in the orthodox way by means of a transformer.

An exception to this is the 10 K. W., ten pole, single phase, Slattery alternator belonging to the electrical engineering department of the University of Minnesota, which was remodeled last winter according to a plan proposed by Professor Geo. D. Shepardson.

Each of the ten armature coils consists of two flat thirty-two turn layers of No. 16 B. & S. d. c. c. copper wire, laid lengthwise across the smooth, insulated and laminated ring core, and with the ends of the coil bent over the armature heads, as shown by the semi-circular shading in the main drawing. Each coil end is clamped against the flat, insulated brass end-plate by a mica bedded slab of brass fastened with three screws, as shown at coils Nos. 5 and 10. The remaining coils, it will be seen, are held by wider slabs of fiber, each carrying four brass plug-blocks. Only the holes for the fastening screws are shown in the main drawing, the screws being omitted.

The diagrammatic development of the coils appears in heavy solid lines for the upper layer, and in triple line for the lower. Sixteen of the twenty coil terminals are fastened to the middle plug-blocks. The remaining four are left as originally connected, two to each of the leads to the collecting rings; the latter being marked + and — in the drawing.

The field poles occupy positions marked N and S, when a non-lagging current has its maximum instantaneous value. Suppose the lines of force go in the direction of the north pointing end of the compass needle and into the paper, that is into

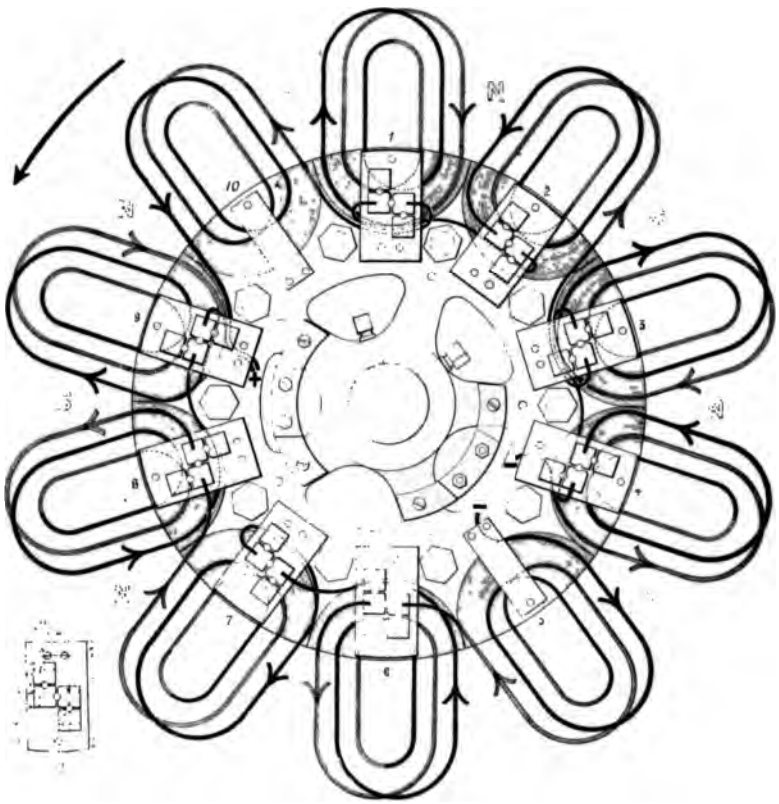


FIG. 1. END VIEW OF ARMATURE.

the armature, at N poles, and come out at S poles. Let the armature rotate counter clock-wise, as indicated by the arrow. The electro-dynamical rule of thumb gives the conventional direction of generator current flow as indicated by solid and triple line arrow heads. The eight leading middle plug-blocks are then positive, and the following ones negative. When the armature has advanced one-tenth revolution, the direction of the current is reverse; the leading plug-blocks are now all negative, and the following ones positive.

Inner, outer and middle plug-blocks are insulated from each other by a minimum fiber surface distance of about $^{5}/_{16}$ inch, and of moving air $^{1}/_{8}$ inch. If then plugs be inserted between

each pair of middle blocks only, the armature halves are in parallel, each with five coils in series, giving 1000 volts at 1600 revolutions per minute with a field current of 7 amperes. This is the original connection, except that coil terminals were connected directly, with soldered and taped joints.

The inner plug-blocks are slotted to hold in common a bare ⅛ inch brass rod ring. which is jammed tight in the slot by crowding adjacent metal in the block against it. This ring is connected by a short rubber and tape-insulated copper wire with soldered joints to the lead from the collecting ring nearest the armature, at the place marked — in the drawing. In a similar way the eight outer plug-blocks are connected to the outer collecting ring, at the place marked +. Hence, by removing the eight middle plugs and inserting the sixteen outer and inner ones, all ten coils are thrown in parallel, and give 200 volts at the above speed and excitation.

In order not to unbalance the armature, instructor Frank W. Springer made each unit of closely similar form and weight. Each was numbered and weighed, when finished, and pairs most alike in weight were placed diametrically opposite. The fibre was hand-sawed and filed to finished slabs $3\frac{3}{4} \times 2\frac{1}{2} \times \frac{3}{4}$ in. The four plug-blocks on the slab were cast in one piece, which was dressed to size on a flat wooden wheel covered with emery cloth, then placed on its fiber base, and holes, located diagonally, two to each finished block, were drilled and tapped through both metal and fibre for No. 8 brass fastening screws. A sectional view in elevation (fig. 2) shows how deeply the heads of these screws are countersunk in the fiber, being far removed from the live coil underneath. Through the brass, yet uncut and firmly screwed to the base, three holes for ¼-inch iron screw-plugs were drilled and tapped, continuing some distance into the fiber, as shown in section. The fiber tenaciously grips the threads of the plug and keeps it from rattling loose. The brass was now unbolted and slit into four blocks, whose corners were cut away to give better access for air circulation and cleaning.

They were also cut back under the plugs to diminish surface leakage. In the square corner of each middle block a hole was drilled and tapped for a No. 6 brass screw to bind the coil

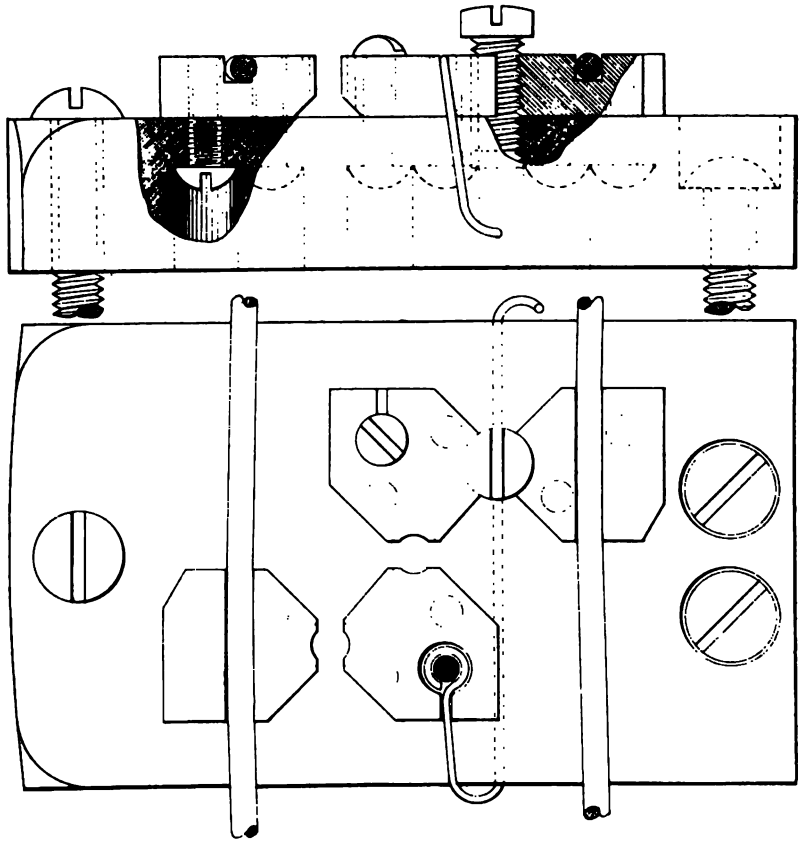


FIG. 2. PLAN AND ELEVATION OF PLUG-BLOCKS AND BASE.

terminal. The latter lies in a groove in the block, curled around the screw and neatly concealed under its head.

The weight of each slab complete is .43 pound. Its center of gravity is about $7\frac{1}{4}$ inches from the axis of rotation. It exerts a centrifugal pull on its fastening screws of about 225 lbs. at 1600 revolutions per minute. The combined elastic shearing strength of the three $\frac{1}{4}$ inch iron fastening screws is about 1500 lbs.

For the brass pieces clamping coils No. 5 and 10 two slabs of fiber were substituted. Each of these carries two dummy brass blocks that are slotted to hold the brass rod rings.

Where necessary, the coil terminals were lengthened with same size wire by soldered copper sleeve joints, and then taped, and shellacked when connected up. In leading them around to their blocks, part were passed through holes drilled in the fiber slabs, as shown in plan and elevation. The wires were very heavily taped wherever they ran close to the bare iron nuts of the bolts that hold core and end-plates together, and also when crossing others of opposite polarity.

When the rejuvenated alternator had been tested, Professor Shephardson ordered the boys to connect it up with the Edison direct current dynamo, on the three wire system, for lighting the Armory 900 feet away. The Edison fed the arc lights, and the alternator, the incandescents, at a reduced speed and excitation, giving 100 volts. The combination worked very well, a slight humming of the enclosed arc lamps being the only unusual occurrence.

THE TWO HUNDRED AND TWENTY VOLT SYSTEM OF ELECTRIC LIGHTING FOR SMALL MUNICIPALITIES.

W. I. GRAY.

This system has been in use in this section of the country for some little time with very good results. It was first introduced in these parts by the Siemans and Halske Electric Co. in a municipal plant installed by them during the summer of 1894 at Adrian, Minn., for street and commercial service. This plant proved a success and many others followed it in rapid succession, until in this state alone there are now about fifteen two hundred and twenty volt plants in successful operation.

The chief reason for the rapid increase in the number of these plants is due to the fact that this system has had so many ardent advocates. There are so many electrical companies that manufacture direct current machinery only, and so few that make the alternating, who do not also make the direct, that the number of its supporters has been greatly in excess of that of any other system. There is no doubt but the inherent qualities of the system afforded its defenders many good talking points, namely, safety, simplicity, direct connected units, higher efficiency of machines, adaptability for both arc and incandescent lamps, good regulation, and small first cost.

There was only one serious drawback to the system, and that was the defects of the incandescent lamp; but all these have since been remedied, except one, and this is the large consumption of current per candle power. This most serious defect is being gradually removed by the lamp manufacturers and the day may not be far distant when this objection will be entirely overcome. When this has been accomplished, then this system, together with the four hundred and forty volt three wire system, will be used almost exclusively for lighting small towns.

The only essential difference between this and any other direct current, two wire, constant potential system of lighting is that of the pressure carried. When the electric current was

first used for incandescent lighting, the voltage was necessarily low, because the art of manufacturing incandescent lamps had not sufficiently advanced to permit of the higher voltages, but ever since that time the pressure has been increasing, until now the voltage used for some lamps is as high as two hundred and fifty, and it may be added that these high voltage lamps are fully as efficient and successful as were the early bamboo filament lamps.

The difficulties encountered in the first incandescent central stations were greatly in excess of those met by the installers of the first two hundred and twenty volt plants, because those handling the higher pressure had the previous experience of lower voltage work, and then too, the manufacture of all classes of electrical appliances had so advanced that there was no scarcity of specialties for any purpose; even if these were not entirely adapted to the higher voltage work, yet, they could be used for the purpose with very good success.

The lamp itself presented to the contractor the greatest number of difficulties, and among the more troublesome of these were short-circuiting at the base, drooping of the filament when the lamp was placed in a horizontal position, crossing of the filament spirals, large candle power at the outset, rapid loss in candle power, and low efficiency. Some of these difficulties could be temporarily overcome by furnishing new lamps and the replacing of fuses, but others were inherent in the filament itself and could only be remedied by the manufacturer. In most towns, the flat rate prevails and the schedules were universally made out for the 16 c. p. lamps, when, in fact, the lamps started out with a candle power of twenty, and as the candle power dropped off, the efficiency decreased so that the station owner always had to furnish too much current for the compensation which he received. These defects have been remedied one by one, until now the lamps can be burned in almost any position, without decrease in life; and short-circuiting rarely, if ever, occurs, taking into consideration only the very best make of lamps.

There are only a very few first-class 220-volt lamps upon the market, and none but the very best of these should be installed. The life of the lamp is very great, many lasting several

thousand hours, even where gasoline engines are used for the motive power and although the eye can detect no variation in the candle power between impulses, yet the voltmeter shows that it does exist and one would naturally expect the life of the lamp to be greatly lessened, which, however, does not appear to be the case.

The inside wiring for this system should be most carefully performed, only the latest and most approved devices being used throughout the installation, and a strict adherence to the latest rules of the National Board of Fire Underwriters should be insisted upon. Only the best glazed porcelain insulators and rubber insulated lamp cord should be used. The rosettes should have solid lugs,—fused double pole with not greater than one-half ampere fuse wire; the fuse break should be the longest obtainable. Not more than ten 16 c. p. lights should be allowed upon any one branch circuit. Each and every branch circuit should be provided with one 25-ampere branch block. The entrance switches should be double pole, of the baby-knife type. The snap switches should be double break single pole, but of the very best spring double break type.

The main and branch blocks should not be less than twenty-five amperes capacity and properly fused for the number of lights. The plug type of cut-out should never be used because of the liability to maintain an arc in the event of a short circuit.

The line work should be of the best construction, all electric light wires passing over all other wires of whatever character. When this is done, bare wire may be safely used for the line work, although in this case automatic magnetic circuit breakers should be placed upon the switchboard to protect each machine. All lines should be protected at the station and at the extremities by proper lightning arresters. In order to insure like pressure on different circuits and to retain the greatest possible amount of copper in the line at all times, one wire should be made common to all circuits and only cut out of circuit when the main double pole dynamo switch is opened at the switch board. The other side of each circuit should have a main single pole long quick-break switch of ample carrying capacity placed upon the switch board. Different circuits can thus be separately controlled at the switch-board with ease

and at the same time keeping the lamps on all circuits at a like brilliancy with a minimum line loss.

The street and inside lighting on this system can be done by means of either arc or incandescent lamps. When incandescent lamps are used for street lighting each individual lamp should be provided with two single pole fuses placed either on the line or in the street hood; if this precaution is taken it will save a great deal of trouble when short circuits take place, which are more liable to occur out of doors owing to the wind and rain. Each individual circuit of arc lamps should be treated in the same manner.

There are three different classes of arc lamps that can be used: the first is the constant potential arc, designed to burn in sets of four. These may be adjusted to give 2,000, or 1,200 nominal, c. p., by means of the resistance in each circuit, but more or less difficulty is experienced with this system of arc lighting, owing to the poor individual lamp regulation, causing lamps in the same set to give out different amounts of light at different times.

Then there are the enclosed arcs that burn in sets of two, across the 220 volts. When lamps of this type, with a series regulating coil, are used, the same difficulty is experienced, but if lamps with a shunt coil are used, this difficulty is overcome and each lamp will burn with a steady and uniform light, independent of its neighbor. The candle power is not so great as with the open arc, but the light is clear and much steadier and, taking all things into consideration, this is perhaps the most satisfactory of the three classes of arcs. Some difficulty is experienced with the sticking of carbons in the cap of the inner globe. Too much care cannot be taken in the selection of carbons for enclosed arc lamps. These lamps draw an arc on about 80 volts, and the current can be regulated by the resistance, so that each group will take the desired current, which may be from four and one-half amperes to six amperes.

The other lamp that is used upon this system draws an arc on 160 volts and requires from 2¼ to 3 amperes. This does not give a very satisfactory light due to the large number of violet rays that are given out. On this account they are not adapted for inside lighting unless two opal globes are used;

these cut off such a large percentage of the light so that satisfactory results are not obtained.

These lamps regulate perfectly, while they burn singly on 220 volts, and would be universally adopted on this account, were it not for their violet rays and the therefore greatly reduced number of white rays that are given out by the lamp for the quantity of energy consumed.

DIRECT CURRENT GENERATORS IN PARALLEL.

FRANK W. SPRINGER.

In almost all electric lighting and power stations it is found necessary, for a part of the day at least, to connect two or more generators to the same line, in order that their combined output may supply a demand which would overtax a single machine. If the generators are of the same make and capacity, and are worked under the same conditions, it is a very easy matter to connect and regulate them in parallel. But, while it is not difficult, and is experimentally quite interesting, to operate a constant current dynamo in parallel with a shunt or compound dynamo, the characteristics of our so-called constant potential machines might be so wholly different as to preclude the possibility of working them in multiple, owing to the continual regulation necessary to keep them adjusted for voltage and division of load.

For instance, if we should connect a dynamo compounded for a rising voltage with increase of load, *i.e.*, overcompounded, in parallel with a plain shunt dynamo, the compound machine would soon be carrying all the load and perhaps running its mate as a motor; and, also, if two shunt dynamos were connected in parallel, one of which held its voltage up with an increase of load better than the other, it is evident that when a load came on the two, the first would take the major part.

The improvement in electrical apparatus has been so rapid that stations built only a few years ago, present dynamo floors as variegated in appearance as Joseph's coat. When the much worried stationman attempts to work any of them together, he finds them as different in other respects as in appearance.

It is necessary, then, to know beforehand the characteristics of generators which are to be paralleled. As these characteristics are best shown by what are called *characteristic curves*, we will outline methods of obtaining the same.

The first is called the Internal Characteristic or Magnetiza-

tion Curve and shows the different voltages of a machine and their corresponding field currents. This curve is taken in order to find the best speed, knowing the voltage at which the machine is to be run.

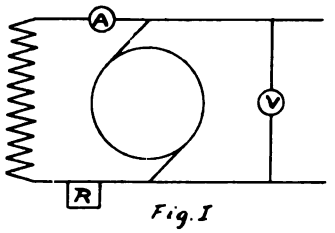


Fig. I

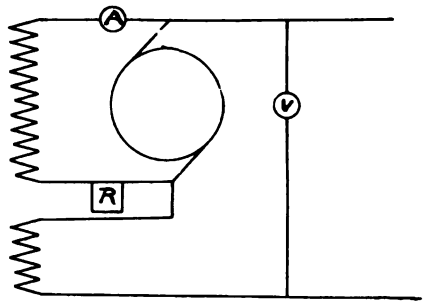


Fig. II

Run the armature at a constant speed. Begin with shunt circuit open and read voltages at the brushes as indicated by V. Next cut resistance out of regulator, R, by successive steps and take readings from A and V simultaneously, sufficient time being allowed before each reading to allow the voltage to become stationary. If, now, having cut out all the resistance in the regulator, R, we take readings after successively increasing the resistance in R, we will get another curve, *d*, Fig. 3, which will differ slightly, from the first, *c*, Fig. 3, *i. e.*, with any given field current we will get a slightly higher voltage in the second case than in the first. This means, in practice, that if we turn our regulating rheostat in one direction to a certain point, we will get a certain voltage, while if we turn our regulator to the same point as before, but coming from the opposite direction, we will get a different voltage, the amount of the difference depending on the point to which we move the regulator, the difference being less as we approach saturation. To illustrate, suppose we decrease our resistance till the combined resistance of the regulator and shunt field is $\frac{110}{1.4} = 78.5$ ohms, we find that our voltage remains stationary at 110 volts and the field current is 1.4 amperes. Now, in the triangle *o m n*, *m n* represents 110 volts, and *o n* 1.4 amperes. Also, $R = \frac{E}{C}$ or $R = \frac{mn}{on}$;

but $\frac{mn}{on}$ is the tangent of angle mon; hence, all points of either curve which lie in the line oi must have the same resistance in the shunt circuit, it being understood, of course, that the armature speed remains constant. If we have a lower resistance than 78.5 ohms in the shunt circuit and increase the resistance so that it is 78.5 ohms, our voltage can be anything between points 80 and 10, on curve C. In other words, our voltage is very unstable. If we take a less resistance, such as corresponds to the tangent of the angle noJ, we find but two voltages for this point on the regulator, namely, (Fig. 3.) 130 on d curve and 120 on c curve. (In order that the tangent of an angle may equal the resistance, volts and amperes must be plotted to the same scale, which was not done in Fig. 3.)

The fact that the voltage falls on one curve and rises on another is an advantage to regulation. For, suppose the voltage rises to 130, then for some reason, such as drop in speed of the engine or weakening of the field due to an increase of current in the armature, or a forward shifting of the brushes, the voltage falls. The fact that it takes less field current to maintain a given voltage, as 130 on curve d, than on c, will of itself balance to some extent the drop; and, conversely, a tendency to rise in voltage is also counterbalanced.

The angles hon and ion may be called critical angles, for, if the resistance of the shunt circuit be greater than that corresponding to the tangent of the angle ion, the dynamo will not build up, and, if the resistance be increased to an amount greater than that corresponding to the tangent of angle hon, the dynamo will unbuild. Hence, if we wish to build up the dynamo, it would evidently be a waste of time to turn our regulator to such a point that the resistance in the shunt circuit would correspond to the tangent of such an angle as jon, for, this angle differing so slightly from the critical angle ion, it is evident, that at any point in the curve, the amount which the voltage of the dynamo would exceed the voltage necessary to maintain the proper amount of current in the field coils for that point on the curve, would be very slight, *i. e.*, the tendency for the field to increase in strength would be slight, because of the smallness of the "growing current." In order to hasten the

building up of a dynamo, cut out all the resistance of the regu-

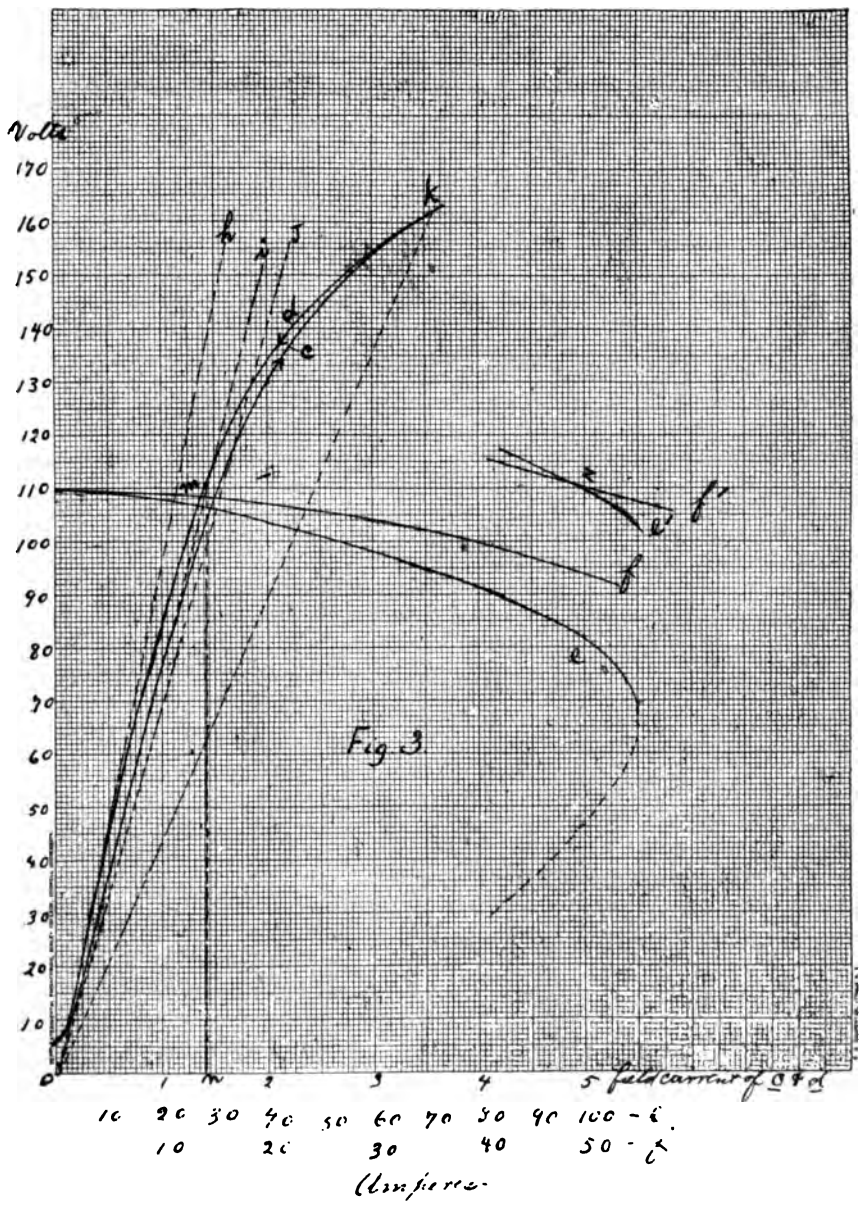


Fig. 3.

lator corresponding to the tangent of such an angle as *k o n*, then catch the voltage as it reaches the desired amount and make the final adjustments.

From the above, we see that it is necessary to have our speed low enough, since the voltage varies directly as the speed and field strength, so that we shall not be compelled to hold our voltage on an unstable part of the curve. In this case, (see Fig. 3), our speed is all right if we do not wish to carry much less than 110 volts. In the next place, our speed should be high enough so as not to be compelled to magnetize our field to saturation, for two reasons. In the first place, as can be seen from the curve, it takes 3½ amperes to bring voltage to 160, but only 2 amperes for 130 volts, *i. e.*, it would take too much current, which is not only a loss in itself, but might cause trouble by overheating the shunt coils; and, secondly, it would interfere with regulation as will be seen later.

The next curve to be considered is called the External Characteristic. The method of taking it is the same for both shunt and compound generators. Connect a voltmeter across the terminals of the dynamo at the switchboard and put an ammeter in the main circuit. As the working part of the curve to be obtained will be nearly a straight line, and only a few points will be needed, it may be found possible to take readings by switching on the regular load in sections. If not, a pail of water, two metal plates for terminals and a handful of salt will serve very well as a rheostat for anything below a capacity of 8 or 10 K. W. Build up the dynamo on curve *d* to the voltage at which it is intended to be run; then, leaving the controlling rheostat in this position, increase the external load, care being taken to shift the brushes if necessary, as would actually occur in practice, and read ammeter and voltmeter simultaneously. The result obtained in one case is seen in curve *e*, Fig. 3. If, now, we should take a second set of readings by decreasing the load, the resulting curve would be somewhat lower than *e* and bear the same relation to *c* that *e* does to *d*, *i. e.*, the field would gradually increase in strength as the load went off.

The first thing noticeable about curve *e* is its gradual drop in voltage as the load comes on, and reaching its maximum at 90 amperes, it suddenly begins to fall off; and, if readings were tak-

en further while very slowly increasing the load, it would be found to double back on itself; the voltage approaching *zero*. This drop in voltage with increase of load, is due to three principal causes: first, decrease in the speed of the armature, which in turn is caused perhaps by drop in speed of the engine and slipping of the belt, often aggravated by being soaked with dynamo oil; second, to a weakening of the field caused by the demagnetizing and distorting action of the armature; third, loss due to the resistance of the armature.

It is now evident that with a shunt dynamo, and also with an under-compounded dynamo, it is necessary, in order to put the voltage up as load comes on, to reduce the resistance in the shunt field regulator. With an over-compounded dynamo, of course, instead of a drooping curve, as *e*, the voltage would rise with an increase of load. If, in curve *e*, we should, taking a point for example at 60 amperes and 98 volts, cut out resistance in the field circuit until the pressure were brought up to 110 volts and then add load or decrease it, we would find voltage to rise and fall practically on a line parallel with curve *e*. (We see here the necessity of starting well down on the curve so as to allow for regulation.)

Suppose *f* to be the curve of a second shunt dynamo whose capacity is 50 amperes and we desire to cut dynamo *f* in parallel with dynamo *e* which is already supplying 100 amperes to the line at 110 volts. Dynamo *e* is then working on *e'* curve at point 100 amperes and 110 volts. If we should connect *f* with *e* at a lower voltage than 110, *f* would evidently become a motor, tending to run in the same direction as before, and, if the difference in voltage were slight, doing no greater damage than sparking at the brushes. In a case of this kind, it would only be necessary to decrease the field resistance to cause it to generate. Since the voltage of *e'* rises with a decrease in load, if we cut in *f* with *e* at a much higher voltage than 110, *f* would take considerable of the load, so it would be well not to bring *f* much above 112, *i. e.*, one or two per cent. above *e*, before cutting it in parallel. Also, the brushes of *e* must be set back as far as possible without sparking in anticipation of a decrease in load, and likewise, the brushes of *f* must be set forward. It must be remembered that any change in the position of the

brushes of a generator changes the demagnetizing action of the armature on the field, and if the brush yoke be moved forward, the result will be a drop in voltage, and if backward, a consequent rise, necessitating a readjustment of the field resistance in either case. Having brought *f* up to 112 volts, and making sure that the bus bar voltage is 110, throw in the switch connecting *f* and *e* in parallel. Dynamo *f* will take a small load and the voltage of the bus bars will rise slightly, owing to a reduction of the load on *e*. If there be several dynamos already in parallel on the bus bars, the change in voltage when another is cut in or cut out will be correspondingly less. Now increase the field resistance of *e* and decrease that of *f*, thus gradually shifting the load from *e* to *f*, meanwhile maintaining the bus bar voltage at 110. This load should be divided in the ratio of their capacities, and, if angle *f'ze'* (see Fig. 3) were zero, they would maintain this relation with varying load. In this particular case *f* will hold its voltage more nearly constant than *e*, and since their voltage must remain the same, their terminals being connected to the same bus bars, this divergence, angle *f'ze'*, will show itself in a change in the division of the load, *i. e.*, with an increase, *f* will take a larger part than before.

It might be argued that, since with every change of load a readjustment of brushes and resistances is necessary anyway, it would not be worth while to have curves *e* and *f* brought together; but there are times when it is desirable, and sometimes necessary to have generators in parallel pull together, for instance, in case of a short circuit when the line must be burned clear.

Curve *f* can be brought down to *e* by putting in a suitable resistance in the main circuit of dynamo *f*; but the better way would be to bring *e* up to *f* by winding series coils on dynamo *e*, *i. e.*, under-compounding it.

In order to cut a dynamo out, its load should be shifted to the other generators as explained above, then its switch pulled. In this way we avoid any change in voltage of the bus bars and save switches by opening them with only a small current on, thus avoiding a destructive arcing at switch blades.

The tendency of the voltage of shunt dynamos to drop with increase of load alone makes it possible to work them in

parallel, and wholly unfits them for such work as required by electric railways and power circuits supplying elevator motors and the like, where the load often varies between maximum and minimum, and so rapid is the change that it is impossible to maintain a constant voltage by hand regulation of shunt generators. For such cases, compound generators are used, usually compounded for a constant voltage at some center of distribution distant from the station. They may be connected in parallel as in Figs. 4 or 5, all machines feeding into the same bus bars being connected, as shown, to an equalizer, *E*. This leaves the division of the current among the series coils independent of the current in their respective armatures, their relative con-

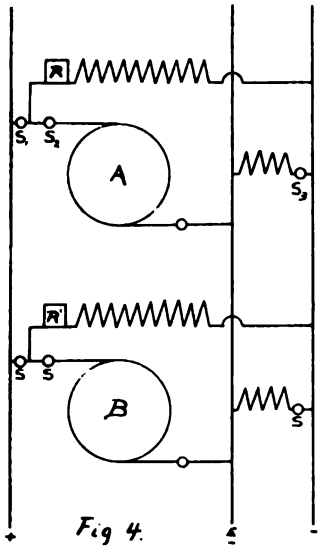


Fig 4.

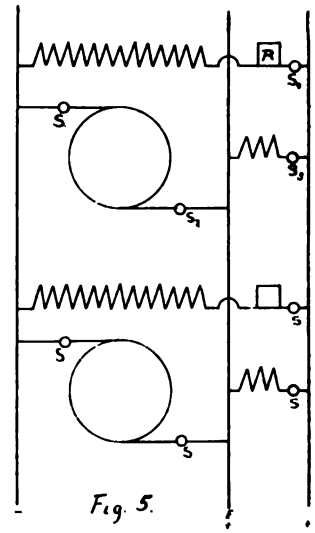


Fig. 5.

ductivities determining this division of current among the fields. For instance, in Fig. 4, suppose *A* and *B* to be generators which are exactly alike, and *A*'s shunt resistance to be so reduced that its armature generates 400 amperes, while *B*'s generates only 100, by virtue of this low resistance equalizer, the series field coils will each carry 250 amperes. This means that 150 amperes current in the series coil of *B* passes along the equalizer and through *A*'s armature. The equalizer has, of course, some resistance and if *A*'s armature generates a larger current than *B*'s, *A*'s series coil will get a little more than *B*'s, but this does

not result in *A*'s field becoming stronger than *B*'s, because the armature reactions and losses, caused by this extra current in the armature of *A*, more than counterbalances such a tendency. The fact that *A* generates more current than *B* is due altogether to the greater current in *A*'s shunt field. Unless the equalizer between *A* and *B* has sufficient resistance to cause enough current to flow about *A*'s series coils to more than make up for the drop in voltage, due to the increased current in its armature, *A* will have no tendency to grab for more load.

Even in a case of motoring, the total current in the series fields and the division of it among them will remain the same as before. For example, increase the shunt resistance of *A* so that *A*'s voltage becomes lower than that of the bus bars; *A* then becomes a motor and current passes through its armature in the opposite direction to that in *B*'s, then along *E* (see Fig. 4.) to the other armatures, heating armatures and connections (C^2R) and causing a drop in the bus bar voltage by the extra armature reactions and losses. None of this local motor current passes through the series coils of any of the machines. If the brushes of the motored generator have the usual forward lead, its field is increased in strength by this current. Thus there is no tendency for motor current to become cumulative.

The motoring of a generator is often accompanied by vicious sparking which is liable to burn holes in the commutator. These holes fill up with carbon and copper dust, finally short circuiting the bars and blowing out, filling up again in a little while and burning deeper the next time.

It is not easy to make generators which are to all appearances exactly alike pull absolutely together under all conditions. They can to a certain extent be adjusted by changing the regulating coils which are placed as shunts around the series coils. These regulating coils shunt current from the other series coils, of course, but being placed on a particular machine affect that machine more than the others, the amount depending on the ratio of the conductivity of the regulating coils to the series coils and on the resistance of the equalizer connecting this machine to the others. Variations due to differences in temperature, being only temporary, must be corrected by adjusting the shunt field rheostats. The brushes should be given, as

nearly as possible, the same lead, although some machines, which do not spark under wide variations in load, can be adjusted by shifting the brush yokes, thus weakening the field more or less by armature reaction.

Compound generators of different makes and capacities, but of the same voltage, can be paralleled with fair success if the following conditions can be obtained: All machines should give the same rise in voltage when their loads are increased from nothing to their respective maxima. The conductivities of their series coils should be in the ratio of their respective maximum loads. Machines which require readjustment of the brushes for slight changes in load cannot be made to give good results. Whether or not the generators meet the above conditions should be determined by separate tests of each. In case the above conditions are not found, they probably can be approximated by one, or some combination of the following changes.

If the resistance of a series coil be too low, resistance can be added; if too high, resistance can be added to all the others. If a coil has too many turns and is of too low resistance, a combination of shunt and series resistances can be used to correct it. If it is desired to increase the rate of rise of voltage for increase in load, the speed of the armature may be increased, thus working the field magnets at a lower degree of saturation, which will make the series coils more effective; conversely, the series coils can be made less effective as in a machine which is over-compounded too much, by running the armature at a lower speed and the field magnets at a correspondingly higher degree of saturation. The over-compounding can also be reduced by putting a suitable resistance in the armature circuit.

The action of generators, after being cut in, is exactly the same whether connected as shown in Fig. 4 or Fig. 5. In Fig. 4, to start a machine, the brushes are dropped on the commutator; switches S_2 and S_3, often combined into a double pole switch, are thrown in; the voltage is regulated by the shunt rheostat until it is 1 or 2 per cent. above the bus bar voltage, when S_1 is thrown in and final adjustments are made as to division of load and setting the brushes. If there are other machines working when S_2 and S_3 are thrown in, the building-up will be greatly

accelerated by the current in the series coil; also, the bus bar voltage will drop, owing to the reduction of current in the series coils of those machines already in use, and in the same way will rise as machines are cut out. This latter is a fact to be remembered when compounding for a certain voltage at a certain point on the line and with a variable number of dynamos in multiple. For, suppose, to take a simple case, we have a generator of a capacity of 500 amperes which will, when working alone, raise the bus bar voltage 10 volts between no load and its maximum, and that this will give us a constant voltage at our center of distribution. If our load now increases so that it becomes necessary to cut in a second dynamo of the same size, we find that our bus bar pressure drops an amount equal to one-half the rise in voltage of the first machine from no load. But our line is of such resistance that it requires a rise of 10 volts for every 500 amperes in order to maintain a constant voltage at our center of distribution.

There are several ways of keeping the rise in voltage proportional to the increase in load with a different number of generators in use. One is to always leave the series coils in, although the armatures may be cut out and stopped. Another, practically the same as the first, is to replace all series coils as they are cut out by coils of equal resistance. A third method which has been proposed, but seems difficult to put in operation and expensive, is to wind series coils on each dynamo of sufficient capacity to carry the total current of all the machines. These coils are then connected in series as their respective machines are cut in.

In Fig. 5, the shunt coils are connected to the bus bars (called bus bar excitation) by a switch. In this case dynamos can be very quickly built up to the desired amount. Switches S_1, S_2 and S_3 are often combined into a three pole switch and are then thrown in together.

THE GILLETTE-HERZOG COMPETITION.

In 1892 the Gillette-Herzog Manufacturing Company established the custom of offering annually, for competition by the students of the Engineering College of the University of Minnesota, a first cash prize of $50 accompanied by a gold medal, and a second cash prize of $30, accompanied by a gold medal.

The conditions of the competition for the present year are:

I. The following subjects will be admitted:

1. Mechanical engineering in such branches as machine design or processes of construction; motor wagons; heating system for building or for large plant; smoke prevention; power generation, transmission or distribution; plan of manufacturing plant, including arrangement and types of machinery, to give best results in plant cost and product cost.

2. Structural (architectual) engineering, as seen in the construction of fire-proof buildings, bridges and iron and steel structures generally. Designs of fire-proof buildings should include the construction of iron and steel roofs and trusses, girders, etc.; bridge designs should give a discussion of the whole question of strains; iron and steel structures should include a comparison of the efficiency of cast iron, wrought iron and steel columns.

3. Municipal engineering, as exhibited in the problem of water supply, e. g., the design of a reservoir or pumping station, with a discussion of the attendant questions of supply and distribution of water.

4. Electrical engineering, particularly in the electric lighting of manufacturing plants and the use of electric motors in such plants.

II. While the competition is open primarily to seniors in mechanical, structural, municipal and electrical engineering, special circumstances may make it advisable to admit graduate students to the competition.

III. The names of ten (10) students selecting suitable subjects shall be presented in good faith as signifying their intention to compete for the prizes before the Gillette-Herzog Manu-

facturing Company shall be bound to declare the prizes open for competition.

IV. The Gillette-Herzog Manufacturing Company and the president of the University shall name the examining board to adjudge the prizes in this competition.

V. The company assumes the right to withold all prizes if, in the opinion of the judges the theses and designs are not of sufficient merit to deserve prizes.

VI. The judges will be expected to decide on the merits of the theses in view of their practical usefulness.

VII. Honorable mention of any theses and designs of special merit, not awarded prizes, may be made by the judges.

VIII. All theses and designs in competition shall be in the hands of the judges on or before May 25th, 1898, and shall be presented in the following manner: Each thesis, accompanied by its designs, shall be handed, without the name of the writer, or any designating mark whatever, to the Dean of the College and by him shall be delivered to one of the judges.

IX. All theses and designs shall be presented in duplicate; one copy shall become the property of the University of Minnesota and the other shall become the property of the Gillette-Herzog Manufacturing Company.

The prizes awarded under each annual offer were as follows:

1892

First prize to Leo Goodkind for a design of a fire-proof building with steel skeleton frame.

Second prize to James H. Gill for a design of a high speed Corliss engine.

1893

First prize to Delos C. Washburn for a design of a steel frame of a machine shop or iron foundry.

Second prize to Frank E. Reidhead for a design of a series electric motor.

1894

First prize to Andrew O. Cunningham for a design of a steel arch bridge.

Second prize to Harriet E. Wells for a design of a wrought iron gate.

Recommended for honorable mention:

Charles H. Chalmers for a design of a 15 h. p. electric motor.
George E. Bray for a design of a steel boiler.

1895

First prize to Leslie H. Chapman for a design of a swing bridge.

Second prize to Harry L. Tanner for a design of an induction motor and a polyphase generator.

1896

First prize to C. Paul Jones for an original design for the steel frame of a 10-story building.

Second prize to C. Edw. Magnusson for specifications for an electric light plant for the Gillette-Herzog Mfg. Co., Minneapolis.

1897

First prize to E. A. Lee for an original design of a Bascule Bridge.

Second prize to C. H. Cross and H. B. Walker for Shearing Strength of Wire Nails.

EDITORIAL

The Engineer's Society has just closed a most successful course of lectures, and though there were not as many given as usual the lack of quantity was made up in quality. Heretofore a fair and reasonable interest has been taken, but it is gratifying to note that the interest and attendance upon lectures this year has been exceptionally good.

Great interest is taken by some of the graduates in helping the society in every possible way and always respond to any favor asked of them by the Society. But there are others who are entirely indifferent to the society's welfare, not even subscribing for the Annual. This is probably due to the fact that after leaving the University the environment is changed from a student's to one of active life, causing the person to lose interest in matters pertaining to questions of interest to Engineering students. But let those who graduate in the future remember that when they leave the University they do so to enter upon a larger field of activity where the only connecting link which binds them to their Alma Mater is the College publications and it is beneficial to them and to the College and to the Society to have them lend what aid they can.

SOCIETY OF ENGINEERS

IN THE

UNIVERSITY OF MINNESOTA.

LIST OF MEMBERS,

MAY, 1898.

HONORARY MEMBERS OF ENGINEERS' SOCIETY.

A. B. Choate.
F. W. Springer, E. E.
Geo. L. Wilson, C. E.
Chas. L. Pillsbury.
C. E. Loweth, C. E.
Morgan Brooks.
E. B. Woodman, C. E.
G. Rosenbusch, B. E. E.
C. W. Hall, M. A.
Wm. R. Hoag, C. E.
Geo. D. Shepardson, M. E.
Wm. R. Appleby, B. A.
Frank H. Constant, C. E.
H. Wade Hibbard, M. E.
A. E. Haynes, Dr. S. C.
H. E. Smith, M. E.
W. H. Kirchner, B. S.
J. H. Gill, M. E.
H. T. Eddy, Ph. D.
F. W. Denton, E. M.

LIST OF ACTIVE MEMBERS OF ENGINEERS' SOCIETY.

Anderson, J. G.
Artz, E. A.
Bailey, G. H.
Blake, H. B.
Brackenbury, C.
Campbell, W. L.
Crickmore, C.
Currier, H. L.
Dahl, H. F. M.
Daniel, T. L.
Davenport, L. B.
Davis, S. E.
Dean, H.
Donaldson, Tho.
Dow, J. C.
Gilchrest, C. C.
Gholz, A. M.
Glass, C. A.
Graling, V.
Grime, E.
Gundstad, I.
Higgins, Chas.
Hildebrandt, H. A.
Hubbell, J. H.
Johnson, F. E.
Jones, E. B.
Keller, F. H.
McAdam, J. V.
McCarthy, E. P.
Midthun, O. J.
Newell, N. W.
Newhall, H. B.
Nye, J. C.
Ober, W. M.
O'Brien, J. E.
Pease, Levi B.
Prendergast, P. S.
Peterson, A.
Pratt, A. C.
Pratt, G. A.
Quense, J.
Queneau, A. L.
Roberts, W. H.
Rogers, A.
Searles, J. E.
Shumway, E. J.
Smith, H. A.
Strale, T. H.
Stussy, W. M.
Sumner, R. B.
Taylor, E. W.
Tracy, T. G.
Van Duzee, E. M.
Wagner, A.
Walker, C. L.
Wardell, E. S.
Warren, J. H.
Wennerlund, E. K.

McIntosh, J. B.
McKellip, F. W.
McKittrick, J.
MacKusick, E. M.
Merrill, R. W.
Whitman, E. A.
Wilson, M. F.
Woodward, C. E.
Wright, Roy V.
Wright, W. H.

CORRESPONDING MEMBERS.

NAME AND RESIDENCE.	DEGREE.	OCCUPATION.
		1875.
Leonard, Henry C. (B. S. '78.) Minneapolis, Minn.	B. C. E.	Physician.
Rank, Samuel A..... Central City, Col.	"	Civil and Mining Engineer.
Stewart, J. Clark ..... Minneapolis, Minn.	"	Physician; Prof. of Pathology at University of Minnesota.
		1876.
Gillette, Lewis S..... Minneapolis, Minn.	B. C. E.	President of the Gillette-Herzog Manufacturing Co.
Hendrikson, Eugene A..... St. Paul, Minn.	"	Lawyer.
Thayer, Chas. E..... Minneapolis, Minn.	"	Grain Dealer.
		1877.
Pardee, Walter S..... Minneapolis, Minn.	B. Arch.	Architect.
		1878.
Bushnell, Charles S..... Minneapolis, Minn.	B. M. E.	Bicycle Manufacturer.
		1879.
Dawley, William S..... Chicago, Ill.	B. C. E.	Chief Engineer C. & E. I. R. R.
*Furber, Pierce P.....	"	Died April 6, 1893.
		1883.
Barr, John H..... ..... Ithaca, N. Y.	B. M. E.	Professor of Machine Design, Cornell University.
Peters, William G..... Tacoma, Wash.	B. C. E.	Vice - President Columbia National Bank.
Smith, Louis O..... Le Sueur, Minn.	"	Civil Engineer.
		1834.
Loy, George J..... Spokane, Wash.	B. C. E.	Bridge Contractor.
Matthews, Irving W..... Waterville, Wash.	"	Real Estate and Abstract of Titles.
		1885.
Bushnell, Elbert E..... New York City.	B. M. E.	Dealer in Typewriters.
*Fitzgerald, Patrick T.....	B. C. E.	Died April 2, 1887.
Reid, Albert I..... Racine, Wis.	"	U. S. Inspector of Harbor Improvements.
		1886.
Woodmansee, Charles C. Midway Park, St. Paul.	B. Arch.	Bookkeeper.
		1887.
Andrews, George C..... Minneapolis, Minn.	B. M. E.	Heating Manufacturer and Contractor.

Crane, Fremont.....B. C. E. Sand Coulee, Mont.	Civil Engineer.
1888.	
Anderson, Christian.....B. C. E. Portland, Ore.	Civil Engineer.
Loe, Eric H.....B. M. E. Minneapolis, Minn.	Mechanical Engineer with Nordyke & Marman.
Morris, John..... " West Pullman, Chicago, Ill.	Mechanical Engineer and Assistant Superintend. of the Plano Mfg. Co.
Hoag, Wm. R. (B. C. E. '84) C. E. Minneapolis, Minn.	Prof. Civil Engineering U. of M.
1889.	
Coe, Clarence S.....B. C. E. Minneapolis, Minn.	City Salesman, Wyman, Partridge & Co.
1890.	
Burt, John L.....B. C. E. Hermosillo, Mex.	Irrigation Engineer.
Dann, Wilbur W.....B. C. E. Minneapolis, Minn.	Assist. Engineer Lake Superior Power Co.
Gilman, Fred H..... " Minneapolis, Minn.	Editor Mississippi Valley Lumberman.
Greenwood, W. W..... " Minneapolis, Minn.	Editor and publisher of The Christian News.
Hayden, John F..... " Minneapolis, Minn.	Editorial Department Mississippi Valley Lumberman.
Higgins, John T..... " St. Paul, Minn.	Physician.
Hoyt, Wm. H..... " Duluth, Minn.	Assistant U. S. Engineer.
Nilson, Thorwald E.....B. M. E. Minneapolis, Minn.	Reporter.
Smith, William C.....B. C. E. St. Paul, Minn.	Assistant Engineer N. P. R. R.
Woodward, Herbert M...B. M. E. Boston, Mass.	Teacher in Mechanic Arts High School.
1891.	
Aslakson, Baxter M.....B. M. E. Dayton, Ohio.	With the Stillwell-Bierce and Smith-Vaile Co.
Carroll, James E.....B. C. E. Minneapolis, Minn.	Draughtsman City Engineer's Office.
Chowen, Walter A..... " Buffalo, N. Y.	Engineer in charge of G. N. elevator.
Douglas, Fred L..... " New York City.	Exam. Eng. Dept. of Buildings.
Gerry, Martin H., Jr., (B. M. E. '90) Chicago, Ill. B. E. E.	Supt. motive power of the Metropolitan West Side Elevated R. R. Co.
Huhn, George P..... " Minneapolis, Minn.	Flour City Nat'l Bank.
1892	
Burch, Edward P.....B. E. E. Minneapolis, Minn.	Electrical Engineer Twin City Rapid Transit Co.
Burtis, William H..... " Decorah, Ia.	Electrical engineer and contractor.
Felton, Ralph P .....B. M. E. Minneapolis, Minn.	Ass't State Y. M. C. A. Secretary.
Goodkind, Leo.....B. Arch. St. Paul, Minn.	City Supt. of schoolhouse construction.

Gray, William I. Minneapolis, Minn.	B. E. E.	Electrical contractor.
Hankenson, John J. Minneapolis, Minn.	B. C. E.	Asst. Engr. C. M. & St. P. Ry.
Higgins, Elvin L. Hutchinson, Minn.	B. C. E.	County surveyor of McLeod Co.
Howard, Monroe S. Waukan, Wis.	B. E. E.	Electrical engineer and contractor.
Mann, Frederick Maynard Philadelphia, Pa.	B. C. E.	Instructor in architectural Design, Univ. of Penn.
Plowman, George T. New York City.	B. Arch.	Sec'y. Goodwin Car Co.

1893

Anderson, Ole J. St. Peter, Minn.	B. C. E.	Civil Engineer.
Avery, Henry B. Minneapolis, Minn.	B. M. E.	With the Gillette-Herzog Mfg. Co. (Engineering dept.)
Bachelor, Frank L. St. Paul, Minn.	B. C. E.	Head draughtsman St. Paul Foundry Co.
Chase, Arthur W. Hastings, Minn.	B. E. E.	Shoe merchant.
Couper, Geo. B. Northfield, Minn.	B. M. E.	Manager Northfield Electric Light Co.
Dewey, William H. New York City.	B. E. E.	Heating Eng. Dewey Eng. Co.
Erf, John W. Middleton, Conn.	B. C. E.	Draughtsman Berlin Iron Bridge Co.
Guthrie, J. DeMott. Elgin, Minn.	B. E. E.	Physician and Surgeon.
Hoyt, Hiram P. Chicago, Ill.	B. C. E.	Draughtsman with American Bridge Works.
Morse, George H. Minneapolis, Minn.	B. E. E.	Instructor in National School of Electricity.
Reidhead, Frank E. Minneapolis, Minn.	"	Supt, East Side Station of Minneapolis General Electric Co.
Springer, Frank W. Minneapolis, Minn.	"	Instructor in University of Minn.
Washburn, D. Cuyler. Minneapolis, Minn.	B. Arch.	Draughtsman for J. T. Fanning, C. E. Specialists on Water Powers.

1894

Bray, Geo. E. Mountain Iron, Minn.	B. M. E.	Electrician for Mountain Iron Mining Co.
Chalmers, Chas. H. Minneapolis, Minn.	B. E. E.	Manufacturer of Electric Machinery.
Cunningham, Andrew O. New Orleans, La.	"	With Gillette-Herzog Mfg. Co.
Gill, Jas. H. (B. M. E., '92)	M. E.	Instructor in Metal Work, U. of Minn.
Gilman, Jas. B. Minneapolis, Minn.	B. C. E.	Draughtsman, Gillette-Herzog Mfg. Company.
Johnson, Noah. St. Paul, Minn.	B. C. E.	C. G. W. Ry. Engineering Dept.
Trask, Birney E. (B. C. E., '90) Highland Park, Ill.	C. E.	Professor of Mathematics, Northwestern Military Academy.
Weeks, William Charles. Minneapolis, Minn.	B. C. E.	U. S. Assistant Engineer.

1895.

Adams, Geo. F. Minneapolis, Minn.	B. E. E.	Electrical Engineering Co.

Crane, Fremont.....B. C. E. Sand Coulee, Mont.	Civil Engineer.
	1888.
Anderson, Christian.....B. C. E. Portland, Ore.	Civil Engineer.
Loe, Eric H.....B. M. E. Minneapolis, Minn.	Mechanical Engineer with Nordyke & Marman.
Morris, John..... " West Pullman, Chicago, Ill.	Mechanical Engineer and Assistant Superintend. of the Plano Mfg. Co.
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Dann, Wilbur W.....B. C. E. Minneapolis, Minn.	Assist. Engineer Lake Superior Power Co.
Gilman, Fred H..... " Minneapolis, Minn.	Editor Mississippi Valley Lumberman.
Greenwood, W. W..... " Minneapolis, Minn.	Editor and publisher of The Christian News.
Hayden, John F..... " Minneapolis, Minn.	Editorial Department Mississippi Valley Lumberman.
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1893

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Erf, John W. Middleton, Conn.	B. C. E.	Draughtsman Berlin Iron Bridge Co.
Guthrie, J. DeMott. Elgin, Minn.	B. E. E.	Physician and Surgeon.
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Morse, George H. Minneapolis, Minn.	B. E. E.	Instructor in National School of Electricity.
Reidhead, Frank E. Minneapolis, Minn.	"	Supt, East Side Station of Minneapolis General Electric Co.
Springer, Frank W. Minneapolis, Minn.	"	Instructor in University of Minn.
Washburn, D. Cuyler. Minneapolis, Minn.	B. Arch.	Draughtsman for J. T. Fanning, C. E. Specialists on Water Powers.

1894

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Cunningham, Andrew O. New Orleans, La.	"	With Gillette-Herzog Mfg. Co.
Gill, Jas. H. (B. M. E., '92)	M. E.	Instructor in Metal Work, U. of Minn.
Gilman, Jas. B. Minneapolis, Minn.	B. C. E.	Draughtsman, Gillette-Herzog Mfg. Company.
Johnson, Noah. St. Paul, Minn.	B. C. E.	C. G. W. Ry. Engineering Dept.
Trask, Birney E. (B. C. E., '90) Highland Park, Ill.	C. E.	Professor of Mathematics, Northwestern Military Academy.
Weeks, William Charles. Minneapolis, Minn.	B. C. E.	U. S. Assistant Engineer.

1895.

Adams, Geo. F. Minneapolis, Minn.	B. E. E.	Electrical Engineering Co.

Bishman, A. E..... Willmar, Minn.	"	Chief Engineer of Lighting Plant.
Bohland, John A..... St. Paul, Minn.	B. C. E.	Draughtsman, Bridge Dept., Gt. Nor. R. R.
Casseday, Geo. A..... St. Paul, Minn.	"	Draughtsman, Bridge Dept., Gt Nor. R. R.
Chapman, Leslie H..... St. Paul, Minn.	"	Bridge Dept., Gt. Nor. R. R.
Cutler, Harry C..... Gibensville, Idaho.	(B. E. M. '94) E. M.	Chemist and Assayer, with American Developing and Mining Co.
Christianson, Peter (B. E. M. '94) Minneapolis, Minn.	E. M.	Instructor, Univ. of Minn.
Eddy, Horace T..... Schenectady, N. Y.	B. E. E.	With General Electric Co.
Rounds, Fred M..... Dallas, Texas.	"	Engineering Dept., Southwestern Tel. and Tel. Co.
Shepherd, B. P..... Minneapolis, Minn.	B. M. E.	Draughtsman.
Tanner, H. L..... Decorah, Iowa.	B. E. E.	Sect. Decorah Electric Light Co.
Tilderquist, William..... Spokane, Wash.	B. M. E.	With Edison Electric Co.
Von Schlegell, F..... Minneapolis, Minn.	B. E. E.	Bridge Dept., Gt. Nor. R. R.
Weaver, A. C..... Minneapolis, Minn.	B. M. E.	Track Recorder, Chi. Gt. West. Ry.
Wilkinson, Chas. Dean.... Whitehall, Mont.	B. E. M.	Manager Gold Hill Mining Co.

1896.

Beyer, Adam C..... Elmira, N. Y.	B. C. E.	Ass't Inspector for The Osborn Company, Cleveland, Ohio.
Burch, Albert M..... St. Paul, Minn.	"	Draughtsman, Bridge Dept., Gt. Nor. P. R. R.
Erikson, Henry A..... Rochester, Minn.	B. E. E.	Teacher.
Hastings, Clive..... Brainerd, Minn.	B. M. E.	Special Machinists' Apprentice, Nor. R. R.
Hilferty, Chas. D..... Allegheny, Penn.	"	Draughtsman, Pitt's Locomotive and Car Works.
Hughes, Thos. M..... Congress, Arizona.	B. E. M.	Mining Engineer.
Hugo, Victor..... Duluth, Minn.	B. M. E.	Mechanical Engineer.
Jones, C. P..... Minneapolis, Minn.	B. C. E.	Civil Engineer.
Lang, James S..... Boston, Mass.	M. E.	With West End Electric R. R. Co.
Long..... Hayland, Georgia.	B. C. E.	Ass't Engineer, Georgia & Florida R. R.
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Table of Contents.

Methods of Transmitting Intelligence, - - - - Geo. D. Shepardson..... 1

The Strength of a Gear Tooth, - - - - - - - - - John T. Flather.....15

A Rotary Converter, - - - - - - - - - - - - Geo. F. Adams... ..25

Theory of the Flexure of a Circular Plate or Ring, Loaded Symetrically About Its Center, - - - - - - - - - - - - Henry T. Eddy.....31

Western Practice for Determination of the True Meridian, - Chas. E. Van Barneweld..... 43

Inspection of Erection of Steel Railway Bridges, - Geo. A. Cassiday.....50

Some Gold in Peru. - - - - - - - - - - - - - Geo. A. Pratt.....54

Laboratory Work in the Electrical Engineering Course at the University of Minnesota, - - - - - - - - - - - - Frank W. Springer.....60

The "Boston and Montana" System of Surveying, - P. B. McIntosh..... 70

Engineering and Finance, - - - - - - - - - - Morgan Brooks..... 78

Water Works for Small Cities and Towns, - - - - - C. F. Loweth.. .. 82

PERUVIAN TUNNELING.—(*Some Gold in Peru.*)

THE

YEAR BOOK

OF THE

SOCIETY OF ENGINEERS

UNIVERSITY OF MINNESOTA.

MAY, 1899.

METHODS OF TRANSMITTING INTELLIGENCE.

GEO. D. SHEPARDSON.

Transmission of intelligence is a subject of enormous importance which has attracted much attention and has called forth the best efforts of inventors, engineers and capitalists. Some idea of the enormous proportions of the service rendered by the public agencies may be gained from a perusal of a few statistics believed to be reliable.

During the year 1896, the United States mail service[1] handled 5,693,000,000 pieces of mail at a cost of something like $90,626,000. The high water mark of the Western Union Telegraph Company, which probably does three-fourths of the business in the United States, was reached in 1893, when it handled 66,591,858 messages[2] for which it received $24,978,000, an average of 35 cents for every man, woman and child in the country. In 1898, the number of conversations conducted through Bell telephones was estimated at 1,231,000,000, from a test count of 3,823,070 exchange connections

(1) Transactions American Inst. Elec. Eng., Vol. XIV; p. 117.
(2) Western Electrician, XXII:11.

made[3] in a single day. At the end of 1897, the Western Union Telegraph Company[3] had 841,002 miles of telegraph wire in operation, enough to reach to the moon and back and go several times around the earth. At the end of 1898, the various licensees of the American Bell Telephone Company had a total[3] of 772,989 miles of wires, while the lines of the independent companies would doubtless bring this figure up to the lines of the Western Union. Allowing a reasonable amount for the lines of other telegraph companies, would make a total of about two million miles of wires in the United States alone for purposes of communicating by electrical methods. In the city of Chicago alone about 220,000 connections[4] are made daily, which, with an average of 3½ miles of wire per connection, would make about 770,000 miles of wire connected daily in one city for telephonic purposes alone.

Such figures, taken in connection with the frequent reports of telegraphing through space, suggest an interesting study into the methods of communication which have preceded the electrical methods of the present day. The writer therefore ventures to present an outline of some work along this line.

The terms telegraphing (writing afar off) and telephoning (sounding afar off) suggest that *distance* might be a suitable basis for classifying methods of communication. We might therefore think of the plesiophone and plesiograph as being generic terms applying to instruments or methods for communication between persons not far apart, but the difficulty of drawing a definite line between near and far distances renders such a basis unsatisfactory.

A classification into *mediate* and *immediate* methods is likewise unsatisfactory as an ultimate basis of division, since the only methods that might be called immediate (without the aid of external or sensible means of carrying thought from one mind to another) would be telepathy and perhaps methods of communicating sentiments by direct

(3) Electrical World and Engineer, XXXIII:409.

(4) Western Electrician, XXII:9.

contact without the aid of words, very effective methods in special circumstances. Even these methods might be considered as being mediate, for in telepathy the ether is probably the vehicle by which the thoughts are transferred, and the other is impossible without using portions of the corporeal being.

A more promising basis of classification is upon the character of the means of communication, whether or not any record is left, that is, whether it is *transient* or *permanent*. This basis is not entirely satisfactory, since some processes of communication may or may not leave a pernent record and the record may have all degrees of permanency from a few seconds to many centuries.

The most satisfactory basis seems to be upon the faculty by which the communication is received. All methods of communication of ideas may be divided into *sensible* and *super-sensible*; the former including those that may be received by one or more of the five senses; the latter including those that seem to reach the mind directly by such means as clairvoyance, hypnotism, telepathy, and the like, methods with which the ordinary mortal may not meddle with entire impunity, but whose phenomena are discussed[5] in the encyclopedias. These methods appeal to the curious and mystical, but are so mixed with fraud and superstition that it is difficult to distinguish fact from error. It is interesting to recall the yarns that circulated in earlier centuries, such as the "sympathetic telegraph," for which two persons had portions of skin mutually transplanted, letters of the alphabet being tattooed upon corresponding portions; when one wished to communicate with his friend, he would prick with a magnetic needle the letter or letters desired and the skin of his friend would instantly itch[6] under the corresponding letter, no matter how far apart they might be.

Passing the super-sensible methods as being beyond the

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(5) See Johnson's Universal Cyclopedia on Association of Ideas, Clairvoyance, Hypnotism, Suggestion, Telepathy, etc.

(6) References to a number of accounts are given in Fahie's History of Telegraphy, pages 10 to 25.

scope of the present study, the most satisfactory basis upon which to classify the sensible methods of communication is the various senses by which ideas may be received. Some will affect two or more senses at once, so that even this basis is not perfect.

We may dismiss the sense of taste as a means of communication, since no such use appears except perhaps as an intermediate agency, the way to a man's heart being reputed to be through his stomach.

The sense of smell is used by the lower animals more extensively than by man. The indians are said to be able to follow a person's trail being guided largely by scent. Stephen Powers[7] testifies from personal knowledge that the Miwok Indians in California sometimes hang the carcases of the unmentionable Mephitis Mephitica on trees along trails difficult to follow, so that they may be guided by one sense, if not by another. Less unsavory is the means by which we frequently learn what Inga is cooking for dinner.

The sense of touch is used most extensively by blind persons, who are able to read through their finger ends. Much information or sentiment is sometimes conveyed by the grasp of the hand. If the sense of touch or feeling be considered to include more than external contact, we might here include a method said to be resorted to by telegraphers in emergency, when they put themselves into the circuit of a telegraph line, and by means of the shocks detect the passing signals. It is conceivable, that when the current is too feeble to affect the ordinary sense of feeling, it might be tasted by the electrolytic effects when the terminals are applied to the tongue. Possibly the sense of touch is effective when deaf persons are enabled to "hear" through a stick or sounding board applied to the teeth or forehead. Much of the so-called mind-reading is doubtless muscle-reading.

By far the most important methods of communicating ideas are those involving sight and sound. Each class may be divided according to whether suitable for conveying words, or simply signals, although the distinction cannot

(7) U. S. Geological Survey Contributions to Ethnology, Vol. 3, p. 351.

be sharply drawn. Probably in the earliest times, men had nothing that could be called words, but expressed their elementary ideas by grunts and sounds which gradually became differentiated into words. In the present stage of civilization, any methods by which sounds or visible signs may be transmitted, is capable of use for sending signals which may indicate words or letters. We may, however, make a general division into those methods that can transmit words as such, and those that can only transmit symbols or signals.

The simplest method of communication by sound is when the voice of the speaker or sender reaches the ear of the recipient through the medium of the air only. By confining the sound waves to one direction or to a limited area, the distance over which the voice can be carried increases. The speaking tube would seem to be the acme in this direction, for it confines the sound to a single direction, but its range is limited by cost and lack of portability. It is said that words spoken in a low tone can be heard at a distance of three-quarters of a mile[8] through a water pipe. Man must have learned at an early date, that his voice could be heard further if his hands were held near the mouth as a sort of funnel; from this idea Kircher (1601-1680) developed the speaking trumpet which is much used at sea and by firemen. Vitruvius, (Cir. 80 A. D.) states that in the theatres[9] of the ancients, resonant brass vessels were placed so as to strengthen the voices of the actors. Alexander the Great is said[10] to have used a funnel through which he gave orders to his troops sometimes eight miles distant. It seems a natural step to reverse the above process and hold the hand behind the ear to reinforce the sound; which plan developed into the ear trumpet. Perhaps the height of sensitiveness and of distance covered by the combination of ear and speaking-trumpet, was reached by Edison, whose megaphone has enabled persons to converse in an ordinary tone of voice when several miles apart. Edison's aerophone

(8) Gillet and Rolfe, Natural Philosophy, page 127.

(9) Ganot's Physics, Sec. 227, p, 185.

(10) Knight, Dictionary of Mechanics, III; 2255, article, Speaking-Trumpet.

is arranged so that the voice causes a diaphragm to vibrate and operate minute valves, which govern the flow of steam through a sort of whistle, by which the sound of the voice is said to be magnified[11] two hundred times. This easily led up to the phonograph[12] by which Edison was able to make a record of words, or other sounds, and to reproduce them at will. The idea of recording and reproducing the human voice may have come from the yarn related by Antiphanes[13] about a city where the cold was so intense that words were congealed as soon as spoken, and were not heard until they thawed out the following summer. The first successful attempt to record words, was by the phonautograph of Leon Scott[14] in 1857, described by Ganot. Twenty years later, Chas. Cros deposited with the French Academy, a description of an apparatus for recording and reproducing sounds[15] which promised to be successful, although it does not appear that he actually constructed it. Edison worked on a somewhat similar plan later, before the paper of Cros was published[16], in September of the same year, making a record by indenting tin foil. Bell and Tainter improved upon it by having a minute knife cut more or less deeply into wax[17], a plan that was also used[18] by Edison. Berliner was an early worker in this field and[18] brought out the gramophone in which the record was made on a disc[19] instead of on a cylinder as used by Edison and others.

The acoustic methods mentioned to this point have been suitable for short distances only, excepting the phonograph, whose records may be sent to any distance and there reproduced. To carry messages further, the system of messengers or couriers was developed centuries ago by Cyrus the Great in 559 B. C. These couriers probably carried written

(11) Cassier's Magazine, III: 445; Elec. World, XIV: 234.
(12) Cassier's Magazine, III: 448; IV:56; Elec. World, XIV: 219.
(13) Cassier's Magazine, III: 449.
(14) Ganot's Physics, Sec. 287, p. 239; also Elec. World, X: 257.
(15) Elec. World, X: 256.
(16) Elec. World, XI: 258; XV:154; Lon. El. Rev., V: 293; Sci. Amer., XXXVII:304, Nov. 17, 1877. Sci. Amer. Sup., No. 133.
(17) Elec. World, XII: 16, 183.
(18) Elec. World, XI:258; XIV: 219; Cassier's Magazine, III: 448; IV: 56.
(19) Elec. World, X: 255; XII: 80; XVII: 6; Trans. Am. Inst. El. Eng., VIII: 19; Jour. Franklin Inst., CXXV: 425, June, 1888; Sci. Am. Sup., July 14, 1888.

messages. A much earlier use was that noted by Job (perhaps 2000 B. C.), who lamented[20] that his days were swifter than a post, and who had learned of his misfortunes through messengers. Oral tradition should be mentioned as one means of carrying ideas over long distances and long periods of time, a method which some thinkers[21] believe to be more accurate than written records.

The term Telephone seems to have been used first by Wheatstone in 1840, in connection with what are now called acoustic, mechanical or lovers' telephones, instruments consisting of a freely suspended wire or tight cord, each end of which terminates at a diaphragm. Sounds near one diaphragm cause it to vibrate and in turn to set up vibrations which are carried along the wire or cord to the second diaphragm, whose vibrations cause sound waves in the air, reproducing the words originally spoken. This device[22] is sometimes operative over distances of a half mile or more.

The electric telephone has been decided by the courts to be the invention of A. G. Bell[23] although the idea was suggested by Bourseul in 1854, and a true telephone was accidentally used by Cushman at[24] Racine, Wisconsin, even earlier in 1851. The work of Ries, Berliner, Gray, Dolbear, Drawbaugh and others may be found in the files of almost any electrical journal. Whatever may be said or believed about the first inventor of the telephone, to A. G. Bell and his associates must be given the credit of having reduced it to a practicable form and of developing it to so great a degree of perfection that it is now possible to talk over a distance[25] of two thousand miles.

Considering next those methods that are suitable for sending signals, but not words, except as some code of signals is used to represent words, it is probable that man early learned to call the attention of those beyond the reach of his voice by whistling. Shells and other crude forms of

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(20) Job IX:25.
(21) Buckle, History of Civilization in England, Vol. I, p. 215.
(22) Elec. World, VIII: 84; XI: 304; XIV: 82.
(23) See electrical journals of 1895.
(24) Univ. of Minn. Year Book, 1894, Vol. II, p. 72.
(25) Electrical World and Engineer, XXXIII:410.

trumpet soon served to increase his range. Instruments of percussion are in common use for attracting attention, as witness the rapping of a pencil on the librarian's desk for quiet, or pounding steam pipes by flat dwellers for steam or quiet. Musical instruments of various sorts may be considered as means of communication, ordinarily of sentiment but sometimes of messages. The bell, used for many centuries for calling people together, seems to have been invented in its modern form in 400 A. D., although small bells were used in the days of Moses[26] and small ones have been found[27] in the ruins of Ninevah. The electric bell seems to have been invented in 1850 by John Mirand[28], thus following the telegraph by several years. The steam whistle has been developed until some of the fog-sirens can be heard from twenty to thirty[29] miles.

That water is an excellent conductor of sound is known to every small boy who has "cracked stones" under water to the discomfort of other bathers within many rods. This property has been used in connection with funnels and bells for communication between ships[30] separated not more than one-half mile.

The electric telegraph is older than the telephone. In its early forms the signals were received by sight entirely, Morse in 1832 beginning the development of a system in which the signals were recorded. Not until after the recording instruments had been in use for several years did it develop that the signals could be received by sound as well as by reading the printed or embossed record. The early history of reading by sound is a matter of controversy, a patent application of Morse in 1837, specifying that "signs or sounds or both" could be used. Otis E. Wood and other operators had learned to receive by sound as early as 1846, but it was not until 1850 that it was adopted[31] by

(26) Exodus, XXVII: 32, 35.

(27) Johnson's Cyclopedia, article on Bells.

(28) Thompson's Electricity and Magnetism, Sec. 508, p. 544.

(29) Johnson's Cyclopedia, article Fog Signals; Knight, Dict. Mech., articles, Fog Signal, Siren.

(30) Maver, American Telegraphy, p. 286.

(31) Elec. World, XVIII:11.

the company. The telegraph has been improved by many inventors, until its history is a large subject. In 1837 Steinbell found that the earth could be used for the return and [32] nearly all the telegraph lines in the world use the single wire system. Morse discovered[33] the relay principle in 1837, although this is claimed[34] for Wheatstone, thus rendering possible the working of long lines. The problem of increasing the capacity of the telegraph lines was attacked by many persons and by various plans. Among those who devised means by which the line should be connected with a number of sending and receiving instruments in succession, were Farmer in 1852, Meyer[35] in 1873, Delaney[36] in 1885 and Patten[37] in 1889. Others have worked along the line known as harmonic telegraphy which is based upon the fact that a reed will respond only to one definite pitch. This seems to have been developed first by Gray[38] in 1874, also by Bell and by La Cour in the same year, the latest plan being proposed by Rowland, in 1899. A quite different course of development was that of transmitting simultaneously from both ends of the line, one message going in either direction. This was started in 1853 by Gintl[39] who was followed by Frischen, Siemens and Halske, Stark, Preece, Edison and a number of others. The success of Frischen in 1854 suggested the possibility of sending two messages in the same direction over one wire. This was attempted by Stark[40] in 1855, whose work was followed by Kramer, Bosscha, Maron, Edison and others. These methods were not successful until 1871, when Stearns[41] of Boston devised a means of obviating trouble from the static charges on the line by using an adjustable condenser at each terminal.

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(32) Turnbull, The Electro-magnetic Telegraph, p. 31.
(33) Reid, The Telegraph in America, p. 78.
(34) Urbanitsky, Electricity in the Service of Man, p. 792.
(35) Prescott, Electricity and the Electric Telegraph, p. 862; Urbanitsky, p. 840.
(36) Delaney, Journal of Franklin Institute, CXVII:49, Jan. 1884; CXXI:91, April 1886; Electrical World, II:291: Maver, American Telegraphy, p. 336.
(37) Patten, Trans. Am. Inst. El. Eng., VI: 111; Elec. Eng., VIII:184.
(38) Prescott, Electricity and Electric Telegraph, pp. 872-880.
(39) Prescott, pp. 768-824.
(40) Prescott, pp. 825-850.
(41) Maver, American Telegraphy, p. 174.

The success of the duplex (sending two messages at the same time in the same direction) and of the duplex (sending two messages simultaneously in opposite directions) suggested the possibility of combining the two and so sending four messages simultaneously on one wire, and the quadruplex was soon the cynosure of much activity. This was accomplished by Edison[42] in 1874, improved upon by Garritt Smith in 1875, later by Prescott, Maver and Davis. Various experimenters have undertaken to increase the speed of the simple Morse system by preparing the messages on paper ribbons which could be passed through an automatic sender at a high rate of speed and be received by some mechanical or chemical device with equal rapidity. The original plan of Morse,[43] was to do this; the message signals being registered by embossing a paper ribbon with a steel point, or by printing with an ink roller or pen, or by chemical action of current passing through the paper. Later workers attempted to use the heating effect of the current to burn the record[44] on the ribbon of paper. The latter plan seems not feasable for fast work, because of the time necessary for the wire to respond to the varying heats. The chemical method has been used extensively, as well as the inking register. Bain, Morse, Davis, Edison, and others have worked along this line, the details of the most successful system in use being worked out by Wheatstone. Recently it has been proposed[45] to use photography and polarised light, by which method, a speed of three to four thousand words per minute is claimed.

Many plans have been tried with some success for sending messages without conducting wires. These methods depend upon conduction, induction or radiation. Messages were sent without wires over a distance of one mile as early as[46] 1842, and have been sent frequently since. The laws governing such telegraphy, have been recently investi-

(42) Prescott, pp. 834-862; Maver, pp. 194-254.

(43) Vail, Amer. Telegraph, pp. 13-40; Turnbull, pp. 61-74; Reid, pp. 38-65.

(44) Horn's method, see Turnbull, p. 142.

(45) Crehore and Squier, Trans. Am. Inst. El. Eng. XIV: 92; El. World, XXXI: 145; Jour. Franklin Inst., CXLV: 161, March, 1898.

(46) Vail, Amer. Tel., pp. 60-63; El. World, XXV: 744.

gated[47] with some care by the German government telegraph department. A more common occurrence is to use induction, which may be either electro-magnetic or electrostatic. The former was used in the method of Phelps for telegraphing[48] to and from railway trains, and is frequently a cause of "cross-talk" on telephone lines. Cross-talk is, however, more commonly caused by electro-static induction as shown[49] by Carty in 1889. By such induction, Dolbear succeeded in 1886 in telephoning[50] a distance of twenty miles[51] between the tops of mountains.

The methods which have been causing much interest in recent years are those depending on the radiation of electric waves, developing the ideas[52] of Maxwell, and the experiments of Hertz. Marconi, with the help of Preece and the British telegraph department, has succeeded in telegraphing messages as far as thirty-one miles without any connecting metallic conductor.

The telegraph was used for the special purpose of a fire alarm system, at an early date after its introduction for public use. Dr. Channing urged its use for this purpose as early as 1839, and in 1851, he succeeded in getting an appropriation from the City of Boston for the purpose of putting in an electric fire alarm system. From this the Gamewell system[53] and others have been developed to their present high state of perfection.

Police telegraph and telephone systems, automatic block signal systems, burglar alarms, time systems and numerous other applications of the telegraph might form subjects for lengthy discussions.

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(47) Elektrotechnische Zeitschrift, XVII: 106, Feb. 13, 1896.

(48) Maver, p. 333; Jour. Franklin Inst., CXX: 165; CXXII: 47; El. World, V: 73; VIII: 234.

(49) Carty, Trans. Am. Inst. El. Eng. VIII: 100; West. Elec. VIII: 181, 210. See also Shepardson, Trans. Am. Inst. El. Eng., August, 1898.

(50) Elec. Eng. V: 422; Elec. World, VIII: 198; Sci. Am. Supp. No. 571.

(51) Telg. Jour., VII: 87; Lon. Elec. Rev. XLIV: 409.

(52) An excellent account of the radiation methods is found in an article in Elec. World, XXXI: 17; also in Lon. Elec. Rev. XL: 812; also in a paper by Marconi in West. Elec. XXIV: 198; Electricity, XVI: 182, 197; Elec. World, XXXIII: 417.

(53) See Bosch, Historical Sketch of the Fire Alarm Telegraph, Trans. Am. Inst. El. Eng. XIV: 335; also publications of the Gamewell Company; also Maver, American Telegraphy, pp. 437-470.

Optical, like acoustic methods of communication, may be divided into transient or permanent, accordingly as a record is left. Ethnologists believe that primitive man conversed by means of signs more than by means of sounds. Certain it is that among uncivilized tribes at present the language of signs[54] seems to be well nigh universal. The flag or its equivalent probably came into use very early. Fire was early used for signalling purposes as noted by Homer[55] and Aeschylus[56] in their accounts of the reports of the fall of Troy. Jeremiah (588 or 612 B.C.) calls upon the Jews to set up[57] a sign of fire as a warning. In later times we recall the warning hung up for Paul Revere, also the common practice of the American Indians. Attempts were made to use fire signals to convey more definite and complicated messages than simple alarms. Polybius (204-122 B. C.) gives an extended account[58] of the methods used by the ancients for telegraphing, including an account of his own plan for spelling out letters and words by a system of torches.

Since the days of Polybius, various schemes have been devised for sending messages by sets of signals by which words might be spelled out letter by letter. Interesting accounts of these have been written by Shaffner[59] Reid[60], Baily[61], Wetter[62], Belloc[63] and others.

The "wig-wag" system of signalling by flags or torches and the heliostat system of using the light of the sun or of an arc lamp, are discussed by Wetter and Maver, also in the books on tactics. The heliograph sometimes has a range as far as one hundred miles[64] when an eight inch mirror is used.

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(54) See Tylor, Early History of Mankind; Starr, First Steps in Human Progress.
(55) Homer, Iliad, Book XVIII, lines 205-214.
(56) Aeschylus, Agamemnon, lines 20-30, 255-305, 460-485, 570-575.
(57) Jeremiah, VI:1.
(58) Polybius, Histories, Book X, Chapters 42 to 47.
(59) Shaffner, Manual of the Telegraph; Shaffner, Telg. Companion, I: 86.
(60) Reid, Telegraph in America, pp. 1-7.
(61) Baily, Lon. Elec. Review, XII:263.
(62) Wetter, Traite de Telegraphie Optique.
(63) Belloc, La Telegraphie Historique.
(64) A. S. Wynne, on Heliography and Signalling in Van Nostrand's Engineering Magazine, XXIII:479-490, Dec. 1880.

Semi-transient visual methods of communication include the use of flags or lights as distinguishing marks for ships, railway semaphores, weather signals, cards for calling express or delivery wagons, blackboard notices, posters and the like; also most forms of recording telegraph, including recording measuring instruments, watchman's recorders, conductor's indicators, calling devices in telephone exchanges and annunciators such as used in hotels and elevators. Light-houses have been in use since the Pharos was built at Alexandria, Egypt, about 300 B. C., or since the siege of Troy, about 1080 B. C., when a signal light[65] was maintained near the Dardanelles.

Methods of visual communication in which the means are permanent, are usually classified[66] under reminders, ideograms and phonograms, including the whole science of written language. It is considered that in the development of written language various sorts of devices were used simply as reminders having little or no inherent connection with the idea to be remembered. The earliest recorded use of such reminder was the mark of warning[67] placed upon Cain. Later followed the rainbow[68] given as a promise to Noah. Holes dug in the ground, notches cut in sticks or trees, strings tied about a finger, sticks put in the pocket and the like, serve simply to remind one that some definite thing is to be remembered. Notches cut in sticks, knots in cords, beads on rosaries to serve as means of counting, blazes cut in trees to indicate roads or trails, all indicate steps toward a more close connection between the sign and the thing to be remembered or communicated to others. Land marks have been heeded[69] since early times. Rude pictures are found in the relics of earliest prehistoric tribes, developing into regular systems of picture writing, interesting examples of which are to be found[70] in the works

(65) Johnson's Cyclopedia, article Light-house.
(66) Isaac Taylor, The Alphabet, Vol. I, pages 1 to 35; Starr, First Steps in Human Progress, pages 192 to 207.
(67) Genesis, IV:15.
(68) Genesis, IX:8-17.
(69) Job. XXIV:2; Deuteronomy, XIX:14; XXVII:17.
(70) See 822 page monograph on Picture Writing of American Indians, by G. Mallory in 10th Annual Report of Bureau of Ethnology of Smithsonian Institute.

of our American Indians. Pictures (or ideograms) soon began to be conventionalized and simplified, then to be used for expressing more or less abstract ideas. Soon symbols were used for sounds and the phonogram came into use. Symbols came to be used to represent entire words, as with the Chinese, or syllables as with the Japanese and some Indian tribes, finally letters came into use. The development of the alphabet has been discussed[71] in an interesting style by Taylor.

Methods of sending written communications have been in use from an early date. Regular relays of messengers were used by Cyrus the Great. Jeremiah (about 595 B. C.) seems to have been familiar with such a system, for in his prophesy he declared[72] that "One post shall run to meet another and one messenger to meet another to show the king of Babylon that his city is taken." The account in Esther a few years later (510 B. C.) states that Mordecai[73] "wrote in the King Ahasuerus' name and sealed it with the king's ring and sent letters by posts on horseback, &c.," to the 127 provinces of the kingdom. The history of the postal system from that time to the present day forms an interesting chapter in the development of civilization. An excellent account of ancient posts and of the development of the English postal system is given by Tegg in his "Posts, Telegraphs and Telephone." The growth of the United States mail service is told by Cushing in "The Story of Our Post Office," also in the encyclopedia under "Postal Service." A comprehensive discussion of this subject would involve us in a study of foot and mounted couriers, wagons, railway systems, street cars, carrier pigeons, steam ships and sailing vessels—in fact, every means of transportation.

The transmission of intelligence, like the transportation of persons and goods, is one of the greatest factors in civilization.

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(71) Isaac Taylor, The Alphabet.
(72) Jeremiah LI:31.
(73) Esther, VIII:10.

THE STRENGTH OF A GEAR TOOTH.

JOHN T. FLATHER.

Much has been written upon this subject and many formulas presented for determining the size of tooth to transmit a given horse power or load, but, the true inwardness of the problem was not properly understood until Mr. Wilfred Lewis presented his excellent paper on this subject before the Engineers' Club of Philadelphia in 1893.*

Previous to this it was generally assumed that the thickness of a tooth measured on the pitch circle was proportional to the strength of the gear.

That this is not so will be readily seen in the following discussion:*

In considering the strength of gear teeth we shall in the first place neglect the actual shape of the tooth and assume it to be rectangular in every section, as shown in Fig. 1.

Further, for the sake of simplicity, it will be assumed that the load, P, acts on the outer circumference of the gear, and hence at the extremity of the tooth. If we consider the conditions under which the load is assumed to be applied in actual practice, we shall find that:

(1) A rough cast gear may have the whole load concentrated upon one corner of a tooth; or the gear itself may be well made, but may be out of alignment, due to springing of shaft, bad workmanship or other causes; in this case also the load may be concentrated upon the corner of one tooth.

(2) The gear may be well made, with accurately cut or cast teeth, well mounted upon heavy shafts having proper alignment; in which case the load may be distributed over the entire breadth of a single tooth.

In determining a formula, then, for the pitch of a gear tooth, we must know the kind of gears we have to deal with and what considerations affect their strength.

* For a more detailed presentation of this subject see article on "Machinery." October and November, 1898.

In the first case if the gear is rough cast or placed so that the load may come upon one corner of a tooth, we must consider not only that the tooth is a cantilever, as in Fig. 1, but

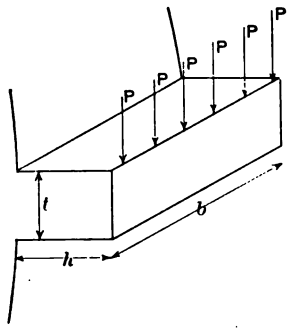


FIG. 1.

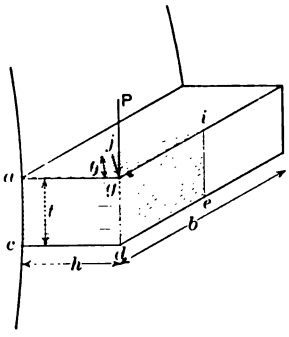


FIG. 2.

that the corner of the tooth itself is a cantilever, as in Fig. 2, in which the whole load, P, is concentrated at the point *g*.

If p = load on corner of tooth;

f = stress in the tooth;

t = thickness of tooth measured on pitch circle,

= 0.48 p′ where

p′ = circular pitch,

it can be shown that

$$p' = 3.6 \sqrt{\frac{P}{f}} \quad \ldots\ldots\ldots\ldots [1]$$

If in any case the width of face, b, is less than the height of tooth, the above formulæ do not apply. In this case we have used the thickness of tooth without considering loss of strength, due to wear; but we have also assumed the whole load as concentrated upon the corner, whereas, as wear occurs, although the tooth itself is reduced in section, yet the load is better distributed and the tooth may be actually stronger.

In the case of rough cast iron and mortise gears in which the whole load may come upon the corner of one tooth, the width of gear does not affect its strength, and there is no

advantage, as far as strength is concerned, in making such a gear wider than $h \times \frac{1}{\cos 45°}$, or 1.41 h; as h, the height of the tooth, is frequently made equal to 7 p′, we have the safe width of tooth, $b = 1.41 \times 7\ p' = p'$ very nearly.

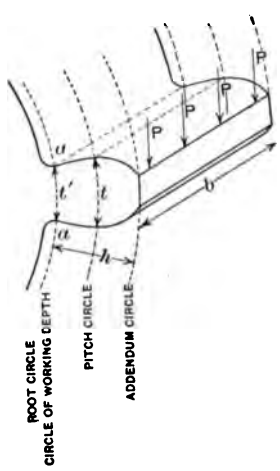


FIG. 3.

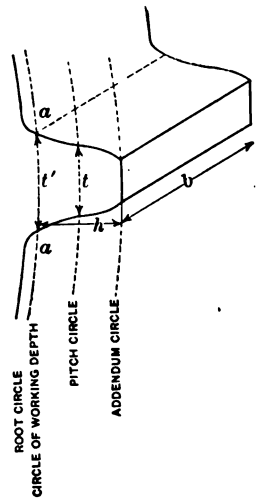


FIG. 4.

In order to prevent excessive wear such gearing is frequently made so that its breadth of face, b, $= 2p'$.

So far we have assumed that the tooth section was a rectangle, but in practice the tooth may have the form shown in Fig. 3, or that in Fig 4, which represent a wide range in the strength of two gears, when accurately made and aligned, but for a load concentrated upon one corner the difference is not so marked as the shape of the teeth would indicate.

Investigation shows that if the smaller of two gears has at least 18 teeth and not more than 50, the strength of the tooth will be practically the same as that determined by the above formulas. Since these values may be said to represent fairly well the limits of the number of teeth in the smaller of two gears in those cases where rough gearing is permissible, we shall not at the present time discuss the in-

fluence of shape upon the strength of this kind of gearing

Of more importance is the consideration of that case in. which the load is supposed to be equally distributed between two pairs of teeth, the inflence of which we believe to be very much over-estimated.

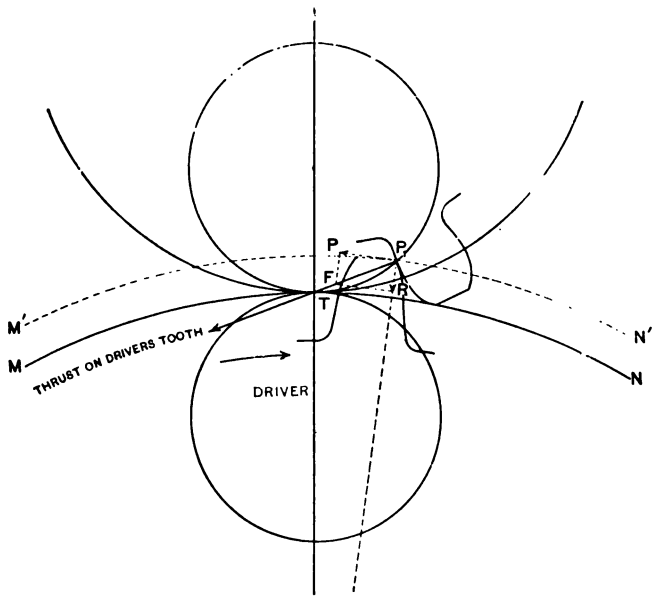


FIG. 5.

As Mr. Lewis has so ably pointed out, it must be admitted that mechanical perfection in forming and spacing has not yet been reached, and that the slightest deviation in either respect is sufficient to concentrate the entire load at the end of one tooth. Even with cut gears the same conditions obtain, for the cutters ordinarily employed are correct only for a single gear, although they are used within certain equidistant limits for various other gears. To what extent the elasticity of bronze, copper and steel influences the distribution of pressure on cut gears is not known, and it is, therefore, unsafe to consider its effect. As the teeth become worn the concentration of the load may be reduced, but until this wear takes place the whole load should be assumed as acting at the extreme end of the tooth.

For rough cast iron and mortise gears, as we have shown, it is possible for the whole load to be concentrated on the corner of one tooth, and this may occur even with the best cut gears, owing to careless alignment or lack of stiffness in the shafting and supports; but when iron patterns are used with accurately cut teeth, especially if the mold is baked, or when the gear is machine molded, or the teeth are cut, the contact should be fairly uniform and the load evenly distributed across the face of the tooth. It must be understood, however, that in many cases circumstances will arise when it is impossible to secure these favorable conditions; particularly is this true when the gearing is subject to shock and variable loads. However, with careful work, stiff shafts and not too wide a face, the assumption of fairly uniform distribution of pressure across the tooth may be considered as satisfactory for general practice.

The pressure which comes upon the tooth in the direction of the line of thrust (the common normal to the tooth surface) is greater than that which transmits motion, for if we resolve the force, F, along and perpendicular to the radius at the point of contact, P_1, Fig. 5, the radial component, R, does not tend to produce rotation; it will, however, exert a pressure on the bearings, and tends to crush the tooth; as the compressive force has little effect upon the strength of the tooth, especially with cast iron gears, its influence may be neglected.

The other component, or P, acts at right angles to the radius and produces rotation by its pressure on the tooth and thus may be considered as the effective working load.

Now considering the tooth as a rectangular cantilever with its load P uniformly distributed across the outer edge, Fig. 1, it can readily be shown that

$$P = 0.066\, f x\, (p')^2 \quad \ldots\ldots [2]$$

and

$$p' = \sqrt{\frac{15\, P}{f x}} \quad \ldots\ldots\ldots\ldots [3]$$

in which x = breadth of face, b, in terms of the circular pitch, that is, $x = \frac{b}{p'}$

It will be noticed that the formulas thus deduced apply only to rectangular teeth, as in Fig. 1, whereas in practice we have to deal with such forms as given in Figs. 3 and 4. In this case the width of tooth is considerably less measured on the working depth circle than on the pitch circle, and fracture would occur between the points a a, where the thickness is t'.

With a uniformly distributed pressure P, acting at the extremity of the tooth as shown, the relative strength of this tooth compared with one of rectangular section having the uniform thickness, t, varies as $\left(\frac{t'}{t}\right)^2$. Thus if a gear tooth of 1 diametral pitch ($p' = 3.14$) measures 1.52'' on the pitch circle, and 1.34'' on the working depth circle, between the points a and a, Fig. 3, the strength of the tooth will be only $\left(\frac{1.34}{1.52}\right)^2 = 0.78$ of that which it would have if the tooth had the constant thickness, 1.52''. In the same way, if the thickness of tooth at a a, Fig. 4, measures 1.76'', its relative strength will be $\left(\frac{1.76}{1.52}\right)^2 = 1.34$. This suggests a convenient method not only of ascertaining the load which a given gear will sustain, but also one which will give a suitable pitch when the load and number of teeth are known.

Since the pitch varies as the square root of the pressure, it will be evident that if we multiply the pitch in each case by the inverse ratio of $\left(\frac{t'}{t}\right)$ we shall obtain a proper measure of the strength of the two teeth, since

$$\frac{1.52}{1.34} = 1.14, \text{ and } \frac{1.52}{1.76} = 0.86,$$

the respective pitches will be 1.14 p' and 0.86 p', in which

$$p' = \sqrt{\frac{15\,P}{f\,x}}$$

It is evident that the method of laying out the gear tooth will have some influence upon its strength; this is very

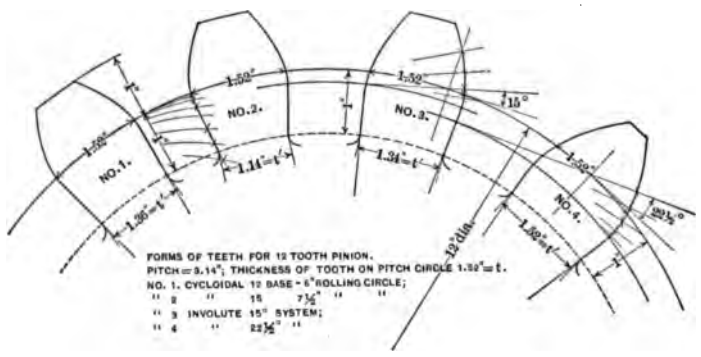


FIG. 6 (REDUCED).

clearly shown in Fig. 6, which represents a twelve-tooth pinion of 3.14 inches pitch accurately drawn for the four systems represented, viz: (1) cycloidal, 12 base, *i. e.*, the smallest pair of gears is assumed to have twelve teeth, and these have radial flanks, so that the diameter of rolling circle is one-half of the diameter of pitch circle of a twelve-tooth pinion; (2) cycloidal, 15 base; (3) involute, 15 degrees line of action, and (4) involute, 22½ degrees line of action.

By laying out a series of equidistant gears, according to the different systems represented, the exact thickness of t' and t may be determined graphically, from which the values of the ratios $\left(\frac{t'}{t}\right)^2$ may be readily ascertained.

This has been done, and the results are given in Tables I and II. in which the ratio is presented in the form of a coefficient corresponding to the number of teeth in the gear.

In these formulas, the effective or working height of tooth was used instead of the total height, which is always somewhat greater, but as the strength of the tooth varies with the square of its thickness, and as this value increases below the working depth circle more rapidly than the increased height of tooth due to the fillet, we are justified in neglecting that portion of the tooth between the working depth and root circles, assuming that a suitable fillet has been used at the base of the tooth.

The formulas here presented will give a close approximation to the working strength of a gear tooth when the pitch and number of teeth are given, provided we know the working stress in the material of which the tooth is composed. This is, however, such a variable factor that it is possible only to suggest limitations covering general conditions, and the judgment of the designer, based on a knowledge of the conditions under which the gear is to work, must modify the general values, as occasion may require. Indeed, it is much more satisfactory to the designer to use a general formula involving a choice of stress than to employ an entirely empirical rule in which the stress is unknown, and which offers no opportunity for variation under varying conditions.

TABLE NO. 1. VALUE OF COEFFICIENT $C = \frac{t}{t'}$.

No. of Teeth in Gear.		Value of Coefficient $C = \frac{t}{t'}$.			
		Involute System.		Cycloidal System.	
Exact.	Intervals.	15°	22½°.	12Tooth Base	15Tooth Base
12	12	1.14	1.00	1.12	1.33
13½	13— 14	1.10	.96	1.08	1.19
15½	15— 16	1.07	.92	1.04	1.10
17½	17— 18	1.04	.88	1.00	1.03
20	19— 21	1.01	.84	.96	.98
23	22— 24	.98	.80	.92	.95
27	25— 29	.95	.76	.88	.92
33	30— 36	.92	.73	.85	.89
42	37— 48	.88	.70	.82	.86
58	49— 72	.84	.68	.79	.83
77	73—144	.80	.66	.76	.80
290	145—Rack	.76	.65	.73	.77

Combining these coefficients with formulas (2) and (3) we obtain

$$P = 0.066\ f\ x\ C\ (p')^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

and

$$p' = C\sqrt{\frac{15\ P}{f\ x}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

In the same way formulas may be deduced for wooden

cogs by assuming the width of tooth equal to .6 p′—a common value.

TABLE NO. 2. VALUES OF COEFFICIENT $C_s = \left(\frac{t'}{t}\right)^2$

No. of Teeth in Gear.		Value of Coefficient $C_s = \left(\frac{t_1}{t}\right)^2$			
		Involute.		Cycloidal.	
Exact.	Intervals.	15°	22½°.	12Tooth Base	15Tooth Base
12	12	.77	1.00	.79	.56
13½	13— 14	.88	1.08	.85	.70
15½	15— 16	.87	1.18	.92	.83
17½	17— 18	.92	1.29	1.00	.94
20	19— 21	.96	1.42	1.08	1.04
23	22— 24	1.02	1.56	1.18	1.11
27	25— 29	1.10	1.72	1.29	1.18
33	30— 36	1.18	1.87	1.38	1.26
42	37— 48	1.29	2.08	1.48	1.35
58	49— 72	1.42	2.16	1.60	1.45
97	73—144	1.56	2.29	1.73	1.56
290	145—Rack.	1.72	2.39	1.87	1.69

An important consideration which the designer must bear in mind in selecting a suitable value of f, is the possibility of serious consequences due to failure. Where the breaking of a tooth would result disastrously, it is evident that a low value of f, or a better material, must be employed; on the other hand, cases will frequently arise in which the circumstances would indicate the use of a high stress with perfect safety.

While high rim speed does not necessarily imply shock, yet the effect of shock is more liable to be disastrous if high speed obtains, and for this reason the stress should diminish as the speed increases. Another reason for this is found in the fact that the stress is increased, due to centrifugal force set up in the metal itself, which varies as the square of the velocity; while this is not very great at ordinary speeds, it is still of sufficient importance to be considered for high speeds.

The influence of change of load is well understood in engineering construction, and usually a factor of safety is

adopted for such loads from two to three times greater than would be the case for a steady or dead load, the value depending largely upon the range of stress involved.

There seems good reason to believe that a similar relation modified by the effect of speed should obtain in selecting a suitable value for the working stress in gear teeth.

From the foregoing considerations, then, it would appear that the working value of f should be chosen both with reference to the velocity and to the character of the acting force.

With this in view the writer has deduced the following empirical formula for working stress:

$$f = \frac{50000}{k + \sqrt[3]{V}}$$

in which f = the allowable stress in pounds per square inch;

V = velocity of pitch point in feet per minute;

k = a constant having the values, 5 for little shock, 10 for moderate shock, and 15 for violent shock.

From this formula Table 3 has been calculated, and is offered as a guide to the designer in selecting suitable values of f under varying conditions:

TABLE NO. 3. VALUES OF STRESS *f* FOR CAST IRON.

Velocity in Feet Per Minute.	Value of Stress in Pounds Per Square for		
	Little Shock	Mod'r'te Shock	Violent Shock
100	5200	3400	2550
200	4600	3150	2400
400	4050	2900	2250
600	3700	2700	2150
800	3500	2600	2050
1000	3300	2500	2000
1400	3100	2350	1900
1800	2900	2250	1840
2400	2700	2150	1770
3000	2600	2050	1700

A ROTARY CONVERTER.

GEORGE F. ADAMS,

The great flexibility of alternating currents as applied to lighting and power is rapidly bringing into universal use the alternating current generator.

High tension with alternating currents is easily and safely obtained thus simplifying the problem of long distance transmission.

By the use of transformers electric lighting, directly from high tension mains, may be accomplished. Synchronous and induction motors are beginning to be used quite extensively, but there still remains the great array of street railway and power motors requiring continuous currents.

Where large electrical units are installed, thereby gaining greater efficiency, alternating current generators are usually chosen, especially when the power station cannot be located near the centre of distribution.

This necessitates some sort of transforming device to convert the alternating into continuous current. This change in form can be brought about either by a direct current generator connected to an alternating current motor or by what is called a rotary converter, a machine which changes alternating currents into direct currents in the same armature.

The latter form is much more efficient, and hence to its development is due the adaptability of alternating currents to all classes of direct current motors.

Rotary converters may be built for changing alternating currents to direct currents at any desired voltage, provided the alternating currents are led in at the proper voltage to maintain the required ratio of conversion. Thus, in a rotary converter built for producing direct currents at 220 volts

the alternating currents would be led in at approximately seven tenths of 220, or 154 volts in the case of single phase alternating currents. This requires step down transformers to reduce the alternating current voltage from the high tension mains.

Rotary converters may be built for any number of phases, the more common being for two and three phases, although single phase rotaries have proven themselves practical. A rotary built for two phases will also run on a single phase circuit.

Only polyphase converters are self-starting; that is, when thrown on to a polyphase circuit, they will start and the speed will gradually increase until finally they fall into synchronism. Two phase and single phase rotaries require some form of starting device outside of the armature of the rotary itself, unless direct currents are obtainable from some other source, when the rotary may be made to start as an ordinary shunt motor.

This article will deal mainly with the description and notes on the operation of a two phase rotary converter built by the Westinghouse Electric and Manufacturing Co., and used for the production of direct currents at 220 and 110 volts.

This will bring out more clearly the statement at the outset that to the rotary converter is largely due the adaptability of alternating currents to all classes of electric installations which consume direct current power, since two voltages may be obtained from the same armature coils at the same time and this too with the ordinary two wire system.

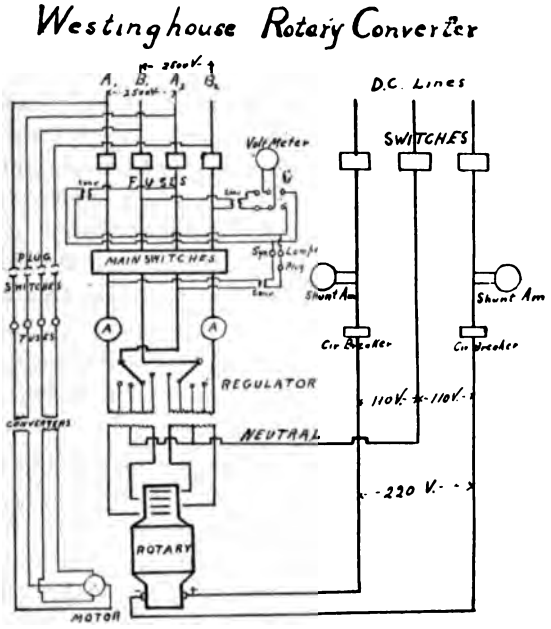
This rotary has a shunt field and has laminated pole pieces. It is rated at 300 K. W.

Following is a diagram of the connections showing the step down transformers, the synchronising device, the voltage regulator, the starting motor and its transformers and the direct current wiring.

The starting motor is built directly on the main armature shaft at the alternating current end.

The method of starting is to throw the motor on the line

and allow it to run up to full speed which is preferably somewhat higher than synchronism. This is provided for by various connections on the motor transformers, giving several voltages so that the speed may be varied if desired. The field of the rotary is then put on and the voltage gradually built up, the speed thereby being reduced until the synchronising lamps indicate that the rotary is in step with the generator at the central station.



The main high tension switch may then be closed and the motor taken out of service, for the rotary will now run as an ordinary synchronous motor. The direct current switches and circuit breakers are then closed and the regular load taken on. It often becomes necessary to vary the direct current voltage. This cannot be done satisfactorily by changing the field of the rotary, although the voltage can be changed to a certain extent by this process for the

ratio of the alternating current voltage to the direct current voltage varies with a variation of the field.

By weakening the field a heavy lagging current is produced and by allowing a greater field excitation a heavy leading current results. But a lagging current produces an armature reaction which is magnetizing and which thereby tends to counteract the lack of field excitation, while a leading current produces an armature reaction which is demagnetizing, thereby tending to counteract the increased excitation, and thus with a constant alternating current voltage from the central station, neither action produces any great change in the direct current voltage.

The need, therefore, of some regulating device is apparent. This is accomplished in the present case by the alternating current regulator as shown in the diagram. It is simply an arrangement whereby a variable ratio of the windings of the primary to the secondary of the transformers may be obtained. Contacts arranged on a dial with a moving arm operated by a lever enables the operator to cut out or cut in, as the case may demand, certain sections of the primary coils. The direct current voltage may thus be regulated through quite a range without any change of voltage at the central station.

The obtaining of two voltages is extremely simple and yet quite novel. The voltage across the direct current brushes is 220 as shown in the diagram. A neutral wire is run from the central point of each transformer and thus it is plainly seen that the voltage between either the positive or the negative terminal and this neutral wire will be one half of 220 or 110. So that a 110 or 220 volt circuit may be run from the substation with the use of only two wires for each circuit.

Considerable difficulty is usually found with rotaries on account of what is called pumping. This is noticeable by the fluctuation of the voltage and a consequent flickering of the lights and a constant vibration of the ammeter needles.

Pumping is due to a complication of causes, but it can be

safely stated that the principal cause is the variable speed of the generator during a single revolution, or, in other words, a variable rate of alternations.

It is easily seen that the speed of an engine-driven generator with two crank shafts set at 90 degrees apart cannot be exactly uniform throughout a complete revolution, since the revolving parts only receive four impulses per revolution. This variable speed causes an alternate rise and fall of the generator voltage and leading and lagging currents are produced.

As has already been stated a leading current produces a demagnetizing effect on the rotary field and thus the direct current voltage would fall while a lagging current produces a magnetizing effect on the rotary field and hence the direct current voltage would rise. The alternate rise and fall of the rotary voltage causes the variation of current and the fluctuation of the lights. This variation is regular and hence the beats are easily distinguishable.

It is noticed that by reducing the field current, the number of pumping beats per minute is preportionately reduced and the variation of the lights is almost imperceptible, but this is not satisfactory since it introduces a heavy lagging current.

A good cure for pumping is to run an induction motor off the same system, for instance, the starting motor may be run continuously without any loss as to the efficiency of the system and the pumping will entirely disappear under most conditions.

The remedy used by the Westinghouse Company, however, is in placing copper rings about the ends of the pole pieces of the rotary with projecting sheaths, which cover the horns, and are slightly imbedded in the face of the pole piece itself. These sheaths take up the armature reaction, eddy currents being set up in them, and thus prevent the variation of the field strength.

The chief objections to rotary converters are, first, the high rate of speed necessary in order to produce the required number of alternations, since the number of poles

is limited; second, the presence of a commutator which is always troublesome, and, third, the close proximity of the brush holders to one another, since a very large commutator cannot be made with safety for such high speeds.

Notwithstanding these objections, the rotary converter has proven itself so satisfactory that it has evidently come to stay, at least until direct current motors are relegated to the past.

THEORY OF THE FLEXURE OF A THIN, FLAT, CIRCULAR PLATE OR RING, LOADED SYMMETRICALLY ABOUT ITS CENTER.

HENRY T. EDDY.

Take the origin of coordinates at the center of the plate and the axis of z perpendicular to the plate. Let the plane of x y bisect the thickness of the plate, and let the thickness = t.

Now consider the flexure of a square elementary portion of the plate situated at a distance r from the center. Let the edges of the square be taken as unity. Let two of the faces be parallel to the radius through the center of the element and two perpendicular to it.

The particles of the plate which lie in the plane x y before flexure, after flexure lie in its neutral plane. Let the flexure be so small that the stretching of the neutral plane may be neglected, then if M_1 = the moment of flexure about x per unit of section along x, and M_2 = the moment of flexure perpendicular to x per unit of section perpendicular to x, we have

$$M_1 = \frac{2 p_1 I}{t}, \text{ and } M_2 = \frac{2 p_2 I}{t} \quad \ldots\ldots\ldots\ldots (1)$$

in which p_1 = the stress per square unit at the extreme fiber perpendicular to x, and p_2 = the stress at the extreme fiber parallel to x. The elementary square portion is regarded in one case as constituting a portion of a beam one unit wide forming a part of the plate whose edges are perpendicular to x, and next as a portion of a beam one unit wide and lying along x.

Again, the general values of the elongations l_1, l_2, l_3, per unit of length in the directions of x y z respectively in terms of the stresses p_1, p_2, p_3, in those directions are shown in the general theory of elasticity to be:

$$El_1 = p_1 - k\,(p_2 + p_3)$$
$$El_2 = p_2 - k\,(p_3 + p_1) \quad \ldots\ldots\ldots\ldots (2)$$
$$El_3 = p_3 - k\,(p_1 + p_2)$$

in which E is Young's Modulus of Elasticity of the material, and k is Poisson's ratio expressing the effect of lateral stresses in producing elongation. Its value for iron and steel is usually about 0.3.

In applying these general equations to a thin plate we may neglect p_3 in comparison with p_1 and p_2.

Hence, if p_3, $=0$ we have from (2):

$$El_1 = p_1 - kp_2, \text{ and } El_2 = p_2 - kp_1 \quad \ldots\ldots\ldots\ldots (3)$$

$$\therefore (1 - k^2)p_1 = E\,(l_1 + kl_2), \text{ and } (1-k^2)p_2 = E\,(l_2 + kl_1) \quad \ldots\ldots (4)$$

Let now R_1 and R_2 be the respective radii of curvature of the beams mentioned previously; they are then the so-called principal radii of curvature of the neutral surface of the bent plate, and by geometry they are seen to be related to l_1, l_2 and t by the equations.

$$l_1 = \frac{t}{2R_1}, \quad \text{and} \quad l_2 = \frac{t}{2R_2} \quad \ldots\ldots\ldots\ldots (5).$$

But by the common theory of flexure we have approximately

$$\frac{1}{R_1} = \frac{d^2z}{dy^2}, \quad \text{and} \quad \frac{1}{R_2} = \frac{d^2z}{dx^2} \quad \ldots\ldots\ldots (6).$$

These values substituted in (5) and the results so found in (4) give the following expressions for the stresses:

$$p_1 = \frac{Et}{2\,(1-k^2)}\left(\frac{d^2z}{dy^2} + k\frac{d^2z}{dx^2}\right),$$
$$p_2 = \frac{Et}{2\,(1-k^2)}\left(k\frac{d^2z}{dy^2} + \frac{d^2z}{dx^2}\right) \quad \ldots\ldots\ldots\ldots (7)$$

These values of p_1 and p_2 are to be introduced into equations (1), but before doing so, it is best to make r the independent variable instead of x and y.

If $x^2 + y^2 = r^2$ we have in general:

$$\frac{d^2z}{dx^2} = \frac{x^2}{r^2}\frac{d^2z}{dr^2} + \frac{(r^2-x^2)}{r^3}\frac{dz}{dr}, \text{ and } \frac{d^2z}{dy^2} = \frac{y^2}{r^2}\frac{d^2z}{dy^2} + \frac{(r^2-y^2)}{r^3}\frac{dz}{dy}$$

But in case the elementary area is situated as proposed at $x = r$ and $y = 0$ we have

$$\frac{d^2z}{dx^2} = \frac{dz^2}{dr^2}, \text{ and } \frac{d^2z}{dy^2} = \frac{dz}{rdr} \quad \ldots\ldots\ldots\ldots (8).$$

If these be introduced into eqs. (7) and the values of p_1 and p_2 so obtained be then placed in eqs. (1) we have finally

$$M_1 = \frac{EI}{1-k^2}\left(\frac{1}{r}\cdot\frac{dz}{dr} + k\frac{d^2z}{dr^2}\right),$$
$$M_2 = \frac{EI}{1-k^2}\left(\frac{k}{r}\cdot\frac{dz}{dr} + \frac{d^2z}{dr^2}\right) \quad \ldots\ldots\ldots\ldots (9)$$

in which $I = \frac{1}{12}t^3$, M_1 is the moment of flexure about r in a plane perpendicular to r, and M_2 in the plane rz about a perpendicular to r.

Having now changed from rectangular to cylindrical coordinates, consider an elementary portion of the plate bounded on the inner edge by an arc of a circle of radius r, and length $rd\theta$, on the two radial sides by faces of length dr, and on the outer edge by a circular arc of length $(r + dr)\, d\theta$.

If the loading of the plate be distributed in the same manner along every radius there will be no shearing stress in any plane rz, but if q = the intensity of the pressure applied in the direction of z to the elementary area $r\, d\theta\, dr$, and S = the intensity of the shear per unit length of section perpendicular to r at the distance r we have

$$q\, r\, d\theta\, dr + \frac{d}{dr} Sr\, d\theta\, dr = 0.$$

But $d\theta$ and dr are constants, hence

$$q\, r + \frac{d}{dr}(Sr) = 0 \quad \ldots\ldots\ldots\ldots (10)$$

Since there is no shearing stress in any plane rz, the couple $M_1\,dr$ acting on one face dr of the elementary area under consideration must be of the same magnitude as that on the other face dr, but they differ in direction by the angle $d\theta$, they consequently differ by an elementary couple whose magnitude is $-M_1\,d\theta\,dr$ acting in the plane rz. If we take this into account together with the shear S, we may write the equation for the variation of M_2 in the plane rz thus:

$$S\,r\,d\,\theta\,dr - M_1\,d\,\theta\,dr + \frac{d}{dr} M_2\,r\,d\,\theta\,dr = 0.$$

$$\therefore Sr - M_1 + \frac{d}{dr}(M_2 r) = 0 \ldots\ldots\ldots\ldots (11)$$

$$\text{By (10) and (11)} \quad \frac{1}{r}\frac{d}{dr}\left(M_1 - \frac{d}{dr}(M_2 r)\right) = -q \ldots\ldots (12)$$

in which q may be constant or variable.

Introduce the values of M_1 and M_2 into (12) from (9).

$$\therefore EI\,\frac{1}{r}\frac{d}{dr}\left[\frac{1}{r}\frac{dz}{dr} + k\frac{d^2z}{dr^2} - \frac{d}{dr}\left(k\frac{dz}{dr} + r\frac{d^2z}{dr^2}\right)\right] = -(1-k^2)q$$

$$\therefore EI\,\frac{d}{dr}\left[\frac{1}{r}\frac{dz}{dr} - \frac{d^2z}{dr^2} - r\frac{d^3z}{dr^3}\right] = -(1-k^2)\,qr$$

$$\therefore EI\,\frac{d}{dr}\left[r\frac{d}{dr}\left(\frac{1}{r}\frac{dz}{dr} + \frac{d^2z}{dr^2}\right)\right] = (1-k^2)\,qr$$

$$\therefore EI\,\frac{d}{dr}\left[r\frac{d}{dr}\left(\frac{1}{r}\frac{d}{dr}(r\frac{dz}{dr})\right)\right] = (1-k^2)\,qr \ldots\ldots\ldots (13)$$

If q be taken to be constant, by integrating etc, successively we find

$$EIr\frac{d}{dr}\left(\frac{1}{r}\frac{d}{dr}\left(r\frac{dz}{dr}\right)\right) = \tfrac{1}{2}(1-k^2)qr^2 + c_1$$

$$\therefore EI\frac{1}{r}\frac{d}{dr}\left(r\frac{dz}{dr}\right) = \tfrac{1}{4}(1-k^2)qr^2 + c_1\log_e r + c_2$$

$$\therefore EIr\frac{dz}{dr} = \frac{(1-k^2)}{16}qr^4 + \tfrac{1}{2}c_1r^2(\log_e r - \tfrac{1}{2}) + \tfrac{1}{2}c_2r^2 + c_3$$

$$\therefore EIz = \frac{(1-k^2)}{64}qr^4 + \frac{1}{4}c_1r^2(\log_e r - 1) + \frac{1}{4}c_2r^2 + c_3\log_e r + c_4 \quad \ldots\ldots\ldots\ldots(14)$$

Let us consider the various parts of the total deflection given by equation (14) as super posed on each other, *i.e.*, let

$$z = z_0 + z_2 + z_3 + z_4$$

1°. If $z_0 = \dfrac{(1-k^2)qr^4}{64EI}$, then by Eqs. (6), (8) and (9),

$$\frac{1}{\rho_{01}} = \frac{1}{r}\frac{dz}{dr} = \frac{(1-k^2)qr^2}{16EI},$$

$$\frac{1}{\rho_{02}} = \frac{d^2z}{dr^2} = \frac{3(1-k^2)qr^2}{16EI}.$$

$$M_{01} = \frac{q}{16}(1 + 3k)\, r^2, \text{ and } M_{02} = \frac{q}{16}(3 + k)\, r^2 \ldots\ldots\ldots\ldots (15)$$

But $k < \frac{1}{2}$, $\therefore M_{01} < M_{02}$, numerically considered.

Also by (11) $$S_0 = \frac{1}{r}\left[M_{01} - \frac{d}{dr}(M_{02}\, r)\right] = -\tfrac{1}{2}\, qr \ldots\ldots (16)$$

2°. If $z_1 = \dfrac{c_1 r^2}{4EI}(\log_\epsilon r - 1)$, then similarly

$$\frac{1}{\rho_{11}} = \frac{1}{r}\frac{dz_1}{dr} = \frac{c_1}{4EI}(\log_\epsilon r - 1), \text{ and } \frac{1}{\rho_{12}} = \frac{d^2 z}{d} \frac{c_1}{4EI}(2 \log_\epsilon r + 1)$$

$$M_{11} = -[2(1 + k)\log_\epsilon r - (1 - k)]\frac{c_1}{4}$$

$$M_{12} = -[2(1 + k)\log_\epsilon r - 1 - k],$$

$$\therefore M_{11} < M_{12}, \text{ also } S_1 = -\frac{c_1}{r}.$$

3°. If $z_2 = \dfrac{c_2 r^2}{4EI}$, then $\dfrac{1}{\rho_{21}} = \dfrac{c_2}{2EI} = \dfrac{1}{\rho_2{}^2}$,

$$\therefore M_{12} = \tfrac{1}{2} c_2 (1 + k) = M_{22} \text{ and } S_2 = 0.$$

4°. If $z_3 = \dfrac{c_3 \log_\epsilon r}{EI}$, $\dfrac{1}{\rho_{31}} = \dfrac{c_3}{EIr^2} = -\dfrac{1}{\rho_{32}}$

$$\therefore M_{31} = \frac{c_3}{r^2}(1-k) = -M_{32}, \text{ and } S_3 = 0$$

5°. If $z_4 = \frac{c_4}{EI}$, this represents a simple displacement of the entire plate such as is obtained by a change of origin and so may be disregarded.

Now in the general case

$$M_1 = M_{01} + M_{11} + M_{21} + M_{31}$$

$$M_2 = M_{02} + M_{12} + M_{22} + M_{32}$$

$$\therefore M_1 = \frac{q}{16}(1+3k)r^2 + \frac{c_1}{4}[2(1+k)\log_e r - 1 + k] + \frac{c_2}{2}(1+k) + \frac{c_3}{r^2}(1-k)$$

$$M_2 = \frac{q}{16}(3+k)r^2 + \frac{c_1}{4}[2(1+k)\log_e r - 1 + k] + \frac{c_2}{r^2}(1+k) + \frac{c^2}{r^2}(1-k)$$

$$S = -\frac{1}{2}qr - \frac{c_1}{r} \quad \ldots\ldots\ldots\ldots (17)$$

But it is evident that in a uniformly loaded plate we must have $c_1 = 0$, for otherwise S becomes infinite at the center where $r = 0$. We must also have $c_3 = 0$ for otherwise the moments of flexure both become infinite when $r = 0$. Hence in this case of uniform load we have

$$M_1 = \frac{q}{16}(1 + 3k)\, r^2 + c_2 (1 + k)$$

$$M_2 = \frac{q}{16}(3 + k)\, r^2 + c_2 (1 + k) \quad \ldots\ldots\ldots\ldots (18)$$

$$S = -\frac{1}{2} qr, \qquad EIz = \frac{1 - k^2}{64} qr^4 + \frac{1}{4} c_2 r^2$$

The maximum value of the shearing stress at the neutral surface will be found in this case to be $\frac{3}{4}\frac{qr}{t}$

Also, $M_2 - M_1 = \frac{q}{8}(1-k^2)\, r^2$, But $1-k^2 > 0$

$$\therefore M_2 - M_1 > 0, \qquad \therefore \text{by eqs. (1)}, \quad p_1 > p_2$$

i. e. the surface tension at any point of the plate is less along the radius than perpendicular to it.

Case 1. Let the edge of the plate rest freely upon a concentric cylindrical support of radius r_1 equal to the exterior radius of the plate. In this case $M_2 = 0$ at $r = r_3$, hence by the second of eqs. (18)

$$0 = \frac{q}{16}(3 + k)\, r_1^2 + c_2 (1 + k) \quad \ldots\ldots\ldots (19)$$

Subtract this eq. from eqs. (18), then

$$M_1 = \frac{q}{16}\left[(1 + 3k)\, r^2 - (3 + k)\, r_1^2 \right]$$

$$M_2 = \frac{q}{16}(3+k)(r^2 - r_1^2)$$

The greatest bending moment numerically is a minimum at $r = 0$ where

$$M_1 = M_2 \text{ at } r = 0 = -\frac{q}{16}(3+k) r_1^2$$

$$\therefore \text{ by eq. (1)} \pm p_1 = \frac{6 M_1}{t^2} = -\frac{3(3+k) qr^2}{8t^2}$$

Now $0.2 < k < 0.4$ for iron and steel,

$$\therefore 1.2 < \frac{p_1 t^2}{q r_1^2} < 1.275$$

from which the numerical value of p_1, the greatest stress at the extreme fiber, can be found within narrow limits.

The magnitude of the total deflection z in this case is found by eqs. (18) and (19) from the following eq.

$$z = -\frac{3 q r_1^4}{8 E t^3 (1+k)}$$

Case 2. Let the plate be firmly clamped along a circumference at a distance r_1 from the center, so that its direction remains unchanged. *i. e.* we have

$$dz / dr = 0, \text{ at } r = r_1$$

$$\therefore 0 = \frac{1 - k^2}{16} q r_1^3 + \frac{1}{2} c_2 r_1, \quad \therefore c_2 = -\frac{1 - k^2}{8} q r_1^2$$

$$\therefore \quad M_1 = \frac{q}{16}\left[(1 + 3k)\, r^2 - 2\,(1 + k)\,(1 - k^2) r_1^2\right]$$

$$M_2 = \frac{q}{16}\left[(3 + k)\, r^2 - 2\,(1 + k)\,(1 - k^2)\, r_1^2\right]$$

The bending moment is a minimum at the centre of the plate and we have at $r = 0$

$$M_1 - M_2 = -\frac{q}{8}(1 + k)\,(1 - k^2)\, r_1^2$$

But $\quad p_1 = 6\, M_1 / t^2 \quad$ and $\quad 0.2 < k < 0.4$

$$\therefore \text{at } r = 0, \qquad 0.864 < \frac{p_1 t^2}{q r_1^2} < 0.882$$

in which p_1 is the greatest stress at the extreme fiber.

At the circle of inflection $M_2 = 0$, hence

$$\frac{r_0^2}{r_1^2} = \frac{2\,(1 + k)(1 - k^2)}{3 + k} \qquad \therefore\ 0.588 < \frac{r_0}{r_1} < 0.6$$

From eqs. (18) and (19) we have at $r = r_1$

$$z = -\frac{3\,(1 - k^2)}{16\, E\, t^3} q r_1^4$$

Case 3. Let r_0 and r_1 be respectively the inner and outer radii of edges of a flat ring loaded with a uniform pressure q lbs. per square inch and resting at its inner and outer

edges upon cylindrical supports on the same level; *i. e.* z has the same value (zero say) at both edges; hence, the left hand member of eq (14) vanishes both at $r = r_0$ and $r = r_1$; and M_2 in eq. (17) also vanishes at r_0 and r_1. After writing out these four equations and placing $c_4 = 0$ we can evidently find the values of c_1, c_2 and c_3 for this case. In fact by eliminating c_2 from the two eqs. first mentioned we find

$$0 = (1 - k^2)(r_1^2 - r_0^2)q + 16c_1 \log_\epsilon \frac{r_1}{r_0} + 64c_3 \left(\frac{1}{r_1^2} \log_\epsilon r_1 - \frac{1}{r_0^2} \log_\epsilon r_0 \right)$$

and similarly from the last two equations

$$0 = -(3 + k)(r_1^2 - r_0^2)\, q + 8\, c_1\, (1 + k) \log_\epsilon \frac{r_1}{r_0} + 16\, c_3\, (1 - k) \left(\frac{1}{r_1^2} - \frac{1}{r_0^2} \right)$$

From these two equations c_1 can be at once eliminated and a value of c_3 found, and then values c_2 and c_1. With given values of r_1 and r_0, the numerical values of c_1, c_2 and c_3 thus found will permit a ready determination of all questions as to stress and strains in the plate.

Case 4. Let the flat ring in case 3 be firmly clamped around each of the edges, then the four eqs. for finding the constants c_1, c_2 and c_3 will be $z = 0$, and $dz / dr = 0$, at $r = r_0$ and $r = r_1$.

These eqs. can be written out without difficulty and the constants determined. The algebraic values are too inconveniently long for space to be given them here, but their numerical values in any special example are readily computed and used.

Case 5. Let the flat ring in case 3 be firmly clamped at the edge $r = r_1$ and simply supported by a stay at $r = r_0$, then $z = 0$ at $r = r_1$ and $r = r_0$; $M_2 = 0$ at $r = r_0$, and $dx / dr = 0$ at $r = r_1$.

Case 6. Let the flat ring in case 3 be freely supported at $r = r_1$ as in case 1, and carry a load P uniformly distributed around the edge $r = r_0$ and acting at right angles to the plane of the plate, but there is no other load acting on the plate, *i. e.* $q = 0$. We then have at the respective edges

$$S_0 = P / 2\pi r_0, \quad \text{and} \quad S_1 = P / 2\pi r_1$$

$\therefore$ by eq. (17) $S_0 r_0 = S_1 r_1 = P / 2\pi = -c_1 \ldots\ldots\ldots (20)$

Moreover in eqs. (17) $M_2 = 0$ at both edges

$\therefore$ by eq. (20)
$$0 = -\frac{P}{8\pi}[2(1+k)\log_\epsilon r_0 + 1 - k] + \frac{c_2}{4}(1+k) + \frac{c^3}{r_0^2}(1-k).$$

$$0 = -\frac{P}{8\pi}[2(1+k)\log_\epsilon r_1 + 1 - k] + \frac{c_2}{4}(1+k) + \frac{c^3}{r_1^2}(1-k).$$

$$\therefore P(1+k)\log\frac{r_1}{r_0} = 4c_3(1-k)\left(\frac{1}{r_1^2} - \frac{1}{r_0^2}\right).$$

$$P(1+k)(r_1^2\log_\epsilon r_1 - r_0^2\log_\epsilon r_0 + \frac{1}{2}P(1-k)(r_1^2 - r_0^2) = 2c_2(1+k)(r_1^2 - r_0^2).$$

The value of c_3 and c_2 thus found, solve all questions in this case.

Case 7. Let the flat ring loaded as in case 6, be firmly clamped at $r = r_1$; then instead of $M_2 = 0$ at $r = r_2$ the equation of condition would be $dz / dr = 0$ at $r = r_1$.

The cases already given will sufficiently point out the steps which need be taken in other cases of pressure combined with loading uniformly distributed along one edge.

It is evident also, that by a similar method, it would be possible to treat the more general case in which q is not a uniform pressure, but is a function of r, *i. e.* $q = f(r)$. The successive integrations of eq. (13) to find z in eq. (14) would then leave unchanged all the terms containing the constants of integration.

WESTERN PRACTICE FOR DETERMINATION OF THE TRUE MERIDIAN,

CHAS. E. VAN BARNEWELD.

The purpose of this article is to describe a method of determining the meridian which is generally adopted throughout the West by U. S. Deputy Mineral Surveyors and Mining Engineers.

The Solar attachment is but little used in our western mining regions. It is claimed that these attachments will give the meridian to within one minute, such accuracy is the exception rather than the rule. They require great care on the part of the Engineer, and even then they can not be relied on for a minimum error of less than three minutes.

The Solar is very useful for rapid and approximate work in unknown or undeveloped districts, where the variation of the magnetic needle is unknown, or where the local attattraction makes the needle useless.

In the last fifteen years the method of Direct Solar observations for the determination of the meridian has gained ground to such an extent in the West, that it has altogether superceded stellar observations.

The principle of the method is simply to ascertain the position of the sun with reference to any line of the survey by the measurement of horizontal and vertical angles. It remains then to calculate by aid of spherical trigonometry the relative positions of the sun and the true meridian at the time the observation is taken. This is then a simple problem in spherical trigonometry, having found three sides of a spherical triangle, to calculate the angle opposite one of these sides.

The spherical angle that enters into our calculation is shown in figures 1 and 2, and is the one between the pole

and the zenith. The sides of this triangle are, first, the arc from sun to pole; second, the arc from zenith to sun; third, the arc from pole to zenith.

As a reminder, the sides of any spherical triangle are arcs of circles, and are measured by the angles opposite these arcs, at the center of the sphere.

In this case the instrument is at the center of the sphere and the three points under consideration are at the surface.

In addition to these arcs, the figures show two other lines, the horizon arc, and the equator arc.

The horizon is of course a horizontal plane that passes through the center of the sphere; the line that passes from the center of the sphere to the zenith is perpendicular to the plane of the horizon.

The equator is simply the earth's equator produced.

The arc from the pole to the equator is equal to the arc from the zenith to the horizon. In the same way, the arc from the pole to the horizon is equal to the arc from the zenith to the equator.

The latitute of the place of observation is represented by the arc subtended by the angle between the horizon and the pole. Hence the arc from the zenith to the equator also represents the latitude.

Fig. 1 shows the sun north or above the equator, and figure 2 shows it south or below the equator. From March 22nd to September 22nd the sun is north of the equator—on the dates given it is crossing it. From September 22nd to March 22nd it is south of the equator.

On the 21st of June and the 21st of December respectively the maximum northern and southern declination is reached.

The angular distance of the sun north or south of the equator is the declination. The first side of the triangle is the arc from pole to sun. This arc is the measure of the co-declination.

It is customary to call the north declination + and the south declination —; then the co-declination will always

be (90° — declination), less than 90° when the sun is north and more than 90° when it is south.

The declination of the sun is found from the nautical almanac, which is published by the Navy Department, at Washington.

The sun's declination for every day at apparent noon (Greenwich), together with the hourly difference is given.

In connection with this it must be remembered that for every 15° west or east of Greenwich, apparent noon is one hour later or earlier than at Greenwich.

To find the co-declination for any day and hour, find the declination at apparent noon (Greenwich) for that day. Calculate the number of hours after noon (Greenwich) to which your time corresponds, and multiply this by the hourly difference. If at the time of observation the sun is receding from the equator (Sept. 22nd to Dec. 21st and March 22nd to June 21st) this product must be added to the declination for the day; if, on the other hand, the sun is advancing toward the equator, this product must be subtracted.

The second side of the triangle is the arc passing from zenith to sun. This arc is the measure of the co-altitude.

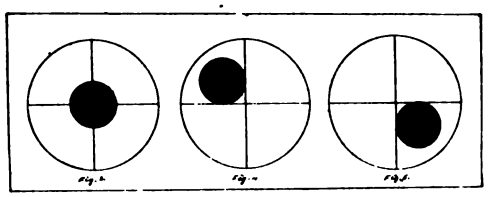
It is found by measuring the altitude of the sun. This altitude will be too high and a correction for refraction must be made. This is always a minus quantity, Correcting the refraction for altitude of the place is an unnecessary refinement.

This corrected altitude of the sun is subtracted from 90°. The remainder is the co-altitude, The necessary correction for the refraction can be found from refraction tables.

Messrs. W. & L. E. Gurley, of Troy, N. Y.; publish a convenient pocket abridgement from the nautical almanac, containing the portion relating to the sun's declination and a table of mean refractions, calculated for latitudes between 2°30′ and 70°, at intervals of 2½°.

There remains the third side of the triangle, namely, the arc from the pole to the zenith.

A glance at figure 1 will show that this arc represents the co-latitude (90° – lat.). Since the distance from the pole to the equator is 90°, and the arc from the zenith to the



equator is the measure of the latitude, the difference between the two arcs, — the arc, pole to zenith, — will be the co-latitude.

In order then to use this method the latitude of the place must be known. If the latitude is not known, it must be first determined.

The angle or azimuth required is formed by two planes intersecting at the zenith, namely, the plane passing through the sun, the zenith, and the transit; and the plane passing through the pole, the zenith and the transit.

Knowing the three sides of the triangle, the required angle may be readily found by applying one of several well known trigonometrical formulae.

The three known sides are:

The co-declination of the sun a

The co-altitude of the sun b

The co-latitude of the place c

Let s denote ½ the sum of the three known sides, then $s = \frac{1}{2}(a + b + c)$.

Let 2 denote the required angle—

Then

$$\text{Sin. } \tfrac{1}{2} Z = \sqrt{\frac{\text{sin. } (s-b) \cdot \text{sin. } (s-c)}{\text{sin. } b \cdot \text{sin. } c}}$$

$$\text{Cos. } \tfrac{1}{2} Z = \sqrt{\frac{\text{sin. } s \cdot \text{sin. } (s-a)}{\text{sin. } b \cdot \text{sin. } c}}$$

$$\text{Tan. } \tfrac{1}{2} Z = \sqrt{\frac{\text{sin. } (s-b) \cdot \text{sin. } (s-c)}{\text{sin. } s \cdot \text{sin. } (s-a)}}$$

Anyone of these formulae will give the azimuth angle measured from the north. Should the azimuth angle from the south be desired, it may be obtained by subtracting Z from 180. For this work the transit must be in good adjustment, and particular care should be taken to make the axis of the telescope bubble to the line of collimation.

The method of proceedure is as follows:

Set up the instrument, and level it approximately with the plate levels. Focus the eyepiece against the sky so that the cross-wires are quite distinct. Carefully finish levelling with the telescope level. Notice whether the vernier of the vertical circle reads zero when the telescope is level. If it does not, correct it, or carefully note the index error in book.

With the vernier of the horizontal circle reading zero, set the cross-wires carefully on the station of your reference line, unclamp both verniers, and point your telescope at the sun.

There are several ways of making the observation. The cross-wires may be made to bisect the sun, or made tangent to the sun's image as shown in figures 3, 4, and 5.

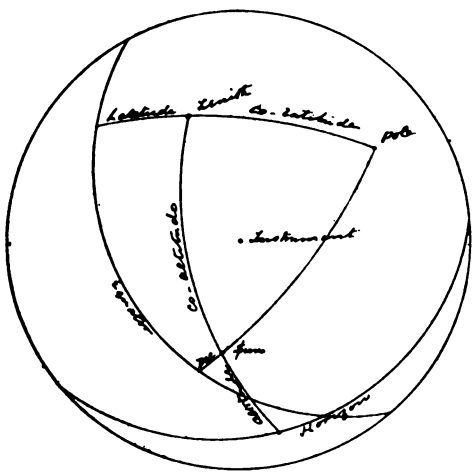


Fig. 1.

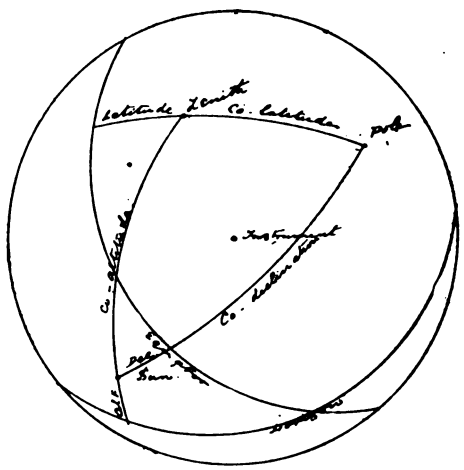


Fig. 2.

If the observation is taken in the forenoon, the sun's image must be taken as indicated by figure 4; if in the after-

noon the opposite corner must be used, as in figure 5.

A piece of smoked glass may be held between the eye and the eyepiece, and the observation taken direct. This method, however, is inconvenient, and may interfere with the clearness of the image.

Some transits are supplied with an arm to which is attached a screen of ground glass. This screen can be adjusted so that it will be at right angles to the line of sight.

The telescope is pointed at the sun until an image of both sun and cross-wires is reflected on the screen. The observer stands behind the ground glass screen and can see the image through it.

Both verniers are then clamped, and by moving the tangent screws the image of the sun is either quartered by the image of the cross-wires (as seen on the glass screen) or made tangent to it. Particular care must be taken at this stage of the observation.

The object glass should be focused to give as large an image of the sun as possible. At the same time this image must be perfectly clear at the circumference.

If no screen is available a white card may be used with equally good results. It is not as convenient, since it must be held in the hand and is not transparent

This method applies only to "erecting" telescopes. With an inverting telescope too large an image of the sun is formed, and a colored prismatic eyepiece should be used. Care must be taken, when using this eyepiece, not to confuse the upper and lower edges of the sun, for the prism erects the inverted image of the inverting telescope and inverts the image of the erecting telescope.

When the desired bisection or tangency has been obtained, note the time, and carefully read the vertical and horizontal angles, note also whether the sun was bisected or whether the cross-wires were made tangent to the sun's periphery. Repeat the operation at least twice, at intervals of not less than five minutes.

It is not desirable to make these observations when the sun is too near the horizon. The refraction of light is then

too great. Neither is it desirable to take it near the noon hour, for then the required angle is too small and a good intersection can not be obtained. No set rule can be made as to the best time for observation. This varies with latitude and contour of the country.

It must be remembered, if the observation is taken on the edges of the sun, that allowance must be made for one-half of the sun's diameter. The diameter of the sun varies from 32.5 minutes to 31.5 minutes during the year. The exact diameter at any particular time can be found in the Ephemeris. One-half of the sun's diameter must be added to both readings in order to obtain the correct horizontal and vertical angle.

A convenient form of keeping the notes is to rule off five columns. The first column is for the station; the second column for the bearing, the third column for the altitude; the fourth column for the point to which the bearing was taken—i. e. center of sun or periphery.

At the top of the page mark the date of observation in case the notes are needed for future reference.

Much may be said for this method. Under favorable conditions (a good transit and reasonable care), extremely accurate results are obtained. One of its great advantages is that a Deputy Surveyor, away from his office, can, with less than half an hour's work, determine the meridian at the beginning of the survey and run all his lines with reference to the true meridian. The computations are simple and are readily made in the field.

The best recommendation for this method is that engineers who have once used it rarely use any other.

INSPECTION OF ERECTION OF STEEL RAILWAY BRIDGES.

GEO. A. CASSEDAY,
BRIDGE INSPECTOR GREAT NORTEERN RAILWAY.

An inspector's duties are to see that work is done in accordance with specifications as interpreted by the engineer in charge.

In the erection of steel railway bridges the inspector's attention is occupied principally with the handling of material and the making of connections.

All heavy members should be handled by power and in unloading or raising should be carefully placed in position. A chord member or plate girder built to carry the heaviest loads may be thrown on its side, and subjected to strains which it was not designed to stand and suffer permanent injury. Small members, gesset plates and projecting parts should never be subjected to a load which will bend, stretch or injure them in any way.

The inspector should check all material on the shipping invoices as it is unloaded to see that there are no missing pieces.

The first step in the erection is the placing of anchorage. Anchor-bolt holes should be drilled at least one-half an inch larger in diameter than the anchor-bolt. They should be drilled in such a manner that the masonry will receive no injury such as splitting or spreading the stones or disturbing the bond. A Z or burr drill will often be safer to work with than the chisel, although it may take longer to do the work. The bolt should be accurrately centered in the hole and grouted. Sulphur, Portland cement, or any other permanent grout may be used. It must be given time to set hard, as any movement before the grout has become thorougly set would destroy the bond.

Masonry or bearing plates should be placed in position with the same care as anchorage. A sheet of lead ¼ inch

thick is probably the most satisfactory medium between the plates and the masonry, since it will flow when a load is placed upon it and conform to any irregularities in the metal or the stone. Portland cement, grout or iron turnings saturated in a solution of sal ammoniac in water may be used. In either case the most satisfactory results are obtained after the structure is assembled by raising the bearing plates with jacks or wedges about half an inch above the cap stones and filling the space with the medium used. Grout should be mixed neat and as thick as it will run. Turnings should be fine and clean and should be tamped into place. Cast turnings or filings are preferable.

In assembling the members of a structure the chief care is to see that all connections are so made that they may develop their full strength. The connections should be examined as the parts are fitted together to see that lengths are accurate. At expansion ends there should be ample clearance for any movement due to changes in temperature which may take place. The parts should be packed as shown on plans. In many cases the positions of eye bars may be changed without causing any difficulty in the erection, but it would change the distribution of stresses and might cause a reduction in the factor of safety of the bridge.

Pilot nuts should be provided for all pins to protect them in driving. Chamfering the end of a pin reduces its bearing area and should be avoided. The threads of bolts should be burred to prevent the nuts from turning loose. All faces of connecting parts which are brought in contact when assembled should first be cleaned and painted.

In riveted work the temporary connections, besides being strong enough to carry their loads with safety, should be so tight that play is impossible. In riveting, the work should be well fitted together and securely pinned and bolted before rivets are driven.

In case the holes do not match they should be reamed to a larger diameter and a larger rivet used. Drifting, which distorts the metal, gauging the holes or reducing the diameter of the rivet to less than $\frac{1}{16}$ of an inch smaller than the diameter of the hole, should not be permitted, Rivets

should be thoroughly heated throughout without burning, should be held in position during driving with a cup faced dolly, should be upset so that the hole is completely filled and should be given a full hemispherical head concentric with the body of the rivet.

There are a variety of ways of testing rivets to determine whether they are tight. The most common way, though not the most accurate, is by ear, there being the same difference in sound between a tight and a very loose rivet as there is between the ring of a silver dollar and a disc of lead. A more satisfactory method is to touch one end of a rivet while the other is struck a light blow with a hammer. If the rivet is loose a slight jar will be felt. The most sensitive test is to hold a piece of metal as a nut or washer on the rivet and strike a light blow as in the former method. In making this test one should be careful not to be deceived as a tap on any part of a plate which is not stayed laterally may be held by holding a weight in contact. A comparison with several shop driven rivets in similar positions will usually determine the accuracy of the test. A loose rivet may be made to seem tight by calking, but this is easily detcted as the marks of the chisel may be seen around the edges of the bead and the results may be destroyed by striking the rivet a hard blow.

In framing ties the daps should be cut with a flat surface to insure a good bearing on the girders and with such accuracy that when in position the rails will have full bearing on each tie. The best results are obtained by planing although no better work than can be done with an adz is usually required. Holes for tie-bolts should be bored after ties are laid and the ends of ties should be sawed off and the guard rail framed after the ties are bolted.

All surfaces should be cleaned before paint is applied. The paint should be thoroughly mixed in proportions as specified. In no case should the use of a drier or thinner be permitted. The paint should be well rubbed into the metal, completely filling all cracks and crevises left in fitting the parts together.

A complete record of the work should be kept, which will

show the number of men employed, their occupation and the daily progress of work. A record of any changes or repairs on account of injuries or inaccuracies should be kept, describing the location and cause of the difficulty, and showing in detail, the condition of the defective part, both before and after the corrections have been made. At all times safety should be considered first. Temporary connections should be secure, and should be examined occasionally until the permanent connection is completed. The old bridge should receive careful attention, as its parts are removed to make room for the new structure. After a bridge is so old that it must be renewed any further weakening might be on the side of danger, and any bracing or member subject to the direct loading of a train, should be kept at least as strong and as securely fastened as it was before the erection of the new bridge was commenced. All passage ways, either in streets or streams, should be kept free from obstructions of any kind which would interfere with traffic, and should be protected from falling bodies or any other source of danger to passers by. After the erection is completed all debris should be destroyed or hauled away. All timber and other material taken out of the old bridge or used in the construction of the new one should be loaded on cars or piled in a convenient place for loading so that the site may be left in as neat a condition as it was before construction was commenced.

SOME GOLD IN PERU.

GEO. A. PRATT.

Starting from Molendo, a port in southern Peru, we took the Ferro Cavlles del Sur railway to Pucara, about 500 miles inland. Tne railway reaches an elevation of nearly 8,000 feet at Arequipa which is at the foot of Mt. Misti. On this mountain is the Howard Observatory in charge of Prof. Bailey.

These mountains over which the railway passes, are metamorphosed granites, resulting schists and gueises showing many stains of copper and silver.

Arequipa, is the headquarters of the large mining interests of southern Peru. Here, many Americans and Englishmen are engaged in business, and they are very cordial to the traveler.

Around Arequipa are deposits of coal, abestos, and gold. The coal is very soft, of a coking character, and has been found unsatisfactory for railroad use. The abestos is a large deposit, of good quality, but of no commercial value, owing to lack of capital. The gold veins are not worked to any extent.

Leaving Arequipa the railway reaches its highest altitude at Censero Alto, 14,660 feet, and then descends to Juliaca which is about 12,000 feet.

Juliaca is a small trading town and a division point on this railway. Around it is found petroleum, but this is not yet worked on a commercial basis.

Near Juliaca at Maraville is one of the two large smelters in Peru. This treats ores of lead, silver and gold, some of which run as high as 70 per cent lead and 30 per cent silver. Most of the silver ores are sulphides and sulphates.

The other important smelter in Peru is located at Lima and treats copper and silver ores coming from a large group of mines around Ceriso de Pasco. The Aurora railway,

which feeds this smelter, reaches the highest elevation of any in the world, something more than 17,000 feet.

The Cayloma Silver mine is also near Julica. This mine has been worked for a long time, and has a mill of an old type for treating its ore. The chloridizing roast is followed by amalgamation, and it may be mentioned that the fuel question is a very important one here. Coal costs $35 per ton delivered at the mine and consequently can not be used. Turf and bituminous slate are used in its stead.

Pucara was the end of our journey by rail, and mules were used for the remainder of the way.

The engines used on the railway had 20 x 21 inch cylinders with five foot drivers, and yet were unable to haul more than four loaded cars over the mountains.

After leaving Pucura we passed through a very mountanous country, over steep roads, and on the fourth day, passed a formation similar to the Basaltic columns. On this same day we happened onto the site of an ancient smelting plant. There was an old reverberatory furnace for chloridizing silver ores, still in good condition. The lines were like those of the modern furnace; firebridge, oval shaped roof, charging holes in the top, and doors on the side for rabbling the charge. The question that arose in connection with this furnace was, what was used for fuel, as the neighboring mountains were entirely devoid of trees. We noticed piles of taquia llama-dung scattered around the pampa. This makes a very hot fire but does not give a radiating heat, and it takes three tons of taquia to equal one ton of coal.

There is also used a moss called yareta. This is a firm compact highly resinous plant which grows on the rocks on the mountain sides. As soon as the rains begin to slacken, this yareta is cut, and dried, and is then ready for use as fuel.

We continued our journey with pleasure and took delight in the grandeur of the scenery. Before us was the snow-capped Mt. Ancoma, some 23,000 feet high and at its base a large sheet of the most beautiful clear blue water—Lake Ancoma. The glaciers here are perhaps not as grand as

those of the Alps; but, to the uninitiated these mountainous bodies of moving snow twisted in lines of every direction, formed a grand spectacle.

From Ancoma Pass (16,000 ft.) begins a decent, at times very abrupt, through the gorge of Limbari River. Many flights of stone steps have to be decended, and to add to the inconvenience of the traveler it is nearly always either raining or snowing.

In about six hours we reached Phara. This is the remains of a once prosperous Spanish villiage. In 1850 it was the center of the gold rush and in past years the Catholic church has taken many hundred pounds of gold out of it.

A word as to the geological formation of these mountains: The formation is quite regular, as the whole Cordillera is a great chain of uplifted schistone slate of the Siberian age. This chain of clay and slate has passed through many conditions of plutonic action—shown by the accidental stratification; and the sedimentary rocks have been changed by metamorphic agents to crystaline rocks. This great band of slate is in many places cut by large quartz veins, and also by granite, porphyry, gueiss and sandstone. There are also large deposits of alluvial earth, consisting of quartz pebbles mixed with gold bearing sands, often stained with iron.

In the two days walk from Phara to Cotani, our final objective point, we passed many milk-white quartz veins with small percentage of Pyrites, and saw old prospect holes all along the trail.

The Sandia Mining Company owns the water rights of two rivers which are some distance apart here but join about thirty miles farther north. The gorges and rivers are narrow and deep and contain many outcroppings of quartz veins. On their right are several well known alluvial deposits which have yielded much gold to the old Spanish conquerors.

These deposits are probably the remains of large lake or river beds, for the rivers have from time immemorial

cut their way through the deposits sifting and settling the gold contents in a natural sluice way.

The great number of massive boulders have served as riffles for collecting the gold for centuries, and it is but reasonable to suppose that the river beds are very rich. Besides this the river beds gain wealth every year during the rainy season, for the high waters scour the hillsides, carrying the surface material into the river. The Indians take advantage of this and build riffles on the banks of the streams during the dry season; then, after the rainy season, they remove the riffles and pan the dirt which sometimes yields several ounces to the pan.

The Scandia Mining Company is constructing a tunnel through a narrow ridge that separates the two rivers at Cotani. The tunnel will be 1,300 feet long by 7 ft. x 7 ft. The slate rock is finely laminated showing here and there small veins. The quartz here has a large percentage of misspickel and this carries gold.

It is the intention to erect dams in each river and alternately run one river through the tunnel into the other. This will leave one river bed dry for three miles in that part where the grade is small.

On the banks of one of these rivers we had an experienced placer miner at work mining a ground sluice. The bank showed up well but the clean up was lacking, and on examination it was found that the murcury and gold did not act with their usual affinity. This may be due to the effects of arsenic as the river sands contain large quantities of mispickle.

The extraction of gold from Para has gone on for some centuries. In 1554 it is noted that a nugget weighing one hundred pounds was sent to Charles V., which had come from Scandia. In the two years following the rush of 1850, something like $5,000,000 worth of gold was extracted.

At Poto there are large alluvial deposits which are worked by hydraulic mining. The main trouble here is the want of water, for, though a large dam has been built, the evaporation is so rapid that little water can be used. A flume several miles long brings the water to the top of

the workings, 100 to 150 ft. high, and it is then conveyed to two monitors by a pipe line. Formerly they resorted to the old Spanish "cockadas" or booming and consequently the valley below is filled with debris. The timber for sluices is obtained from Oregon.

Poto is on the south slope of the Andes and is very cold, while San Juan del Oro on the north side in the valley of the Amazon is quite warm.

The hilly parts of this region are composed of auriferous alluvium cemented by a sandy clay matrix. These beds are from 100 to 400 feet thick rnd rest on a bedrock of slate and sandstone.

The deposits of San Juan are formed of alluvial but the percentage of large stones is smaller than in other deposits and therefore more easily treated. Their value is estimated at 20c per cubic yard and there is plenty of water available with a fall of from 200 to 500 feet.

Other deposits are found at Aporoma which consists of several alluvial hills. On one of these at an elevation of 7500 feet are the remains of a canal, and large tanks for storing water; showing the labor and skill of the builder.

The banks of Aporoma contain larger stones than those of San Juan, but they are more friable. The matrix is a yellowish friable clay which washes well and would give little trouble with clay balls.

The gold is generally found in small circular discs, flat, water worn and covered with rust; consequently some method of scouring would be necessary or a large loss would result from float gold.

The old canals here are in good condition and the water can drain into the Rio Racchani.

The Chaillenna region, two days journey from Cotani, is most noted for its vein mining. The gold occurs in irregular veins of opaque white or yellow quartz, in which the presence of decomposed pyrites is very marked. The country rock is slate mixed with quartz and clay.

The San Domingo vein is at present owned by the Inca Mining Co., an American concern. They have two small five stamp batteries in operation and are taking in a larger

twenty stamp mill now. Great difficulty is experienced in getting the stems and mortars to the mine. The mortars are sectional, but even then are very heavy, and the stems weigh from 200 to 250 pounds. A mule can not pack much more than 150 pounds and a llama not more than 100 pounds.

The ore in this mine is mostly sulphides, carrying about 90 per cent of the gold, and as a free milling process is used only about 10 per cent of the gold is extracted. Yet they ship about 45 pounds of gold every two weeks.

It might be well to mention that petroleum is produced in large quantities at Tilara on the north coast of Peru. Here there are two companies, a French and English. The latter has been quite successful and supplies the railroads with fuel, making a saving to them of about 50 per cent.

In northern Peru some coal deposits are being opened up by the Standard Oil Co., who will run a railroad about 200 miles long to make a connection with the sea coast.

LABORATORY WORK IN THE ELECTRICAL ENGINEERING COURSE AT THE UNIVERSITY OF MINNESOTA.

FRANK W. SPRINGER, E. E.

The technical or engineering college is of recent origin. Less than 25 years ago only the most general courses were given in the sciences. Engineers of that period, if they had a college education at all, were schooled in the classics, philosophy and mathematics. They were thus compelled to get their engineering education from practice, and their success as engineers depended largely on self education and genius. It took many years of practice in which to gather the technical knowledge necessary to success, and consequently engineers were not only well beyond middle age before attaining prominence, but, having very little theoretical knowledge, they were not fitted to meet rapid changes even in their own lines.

Coincident with, and largely on account of, the application of electricity to industrial uses, there arose a great demand for engineers who were adapted by education to keep up with the rapid progress being made in all branches of engineering.

The practical men, as a class, could only do as they had done before, they did not know, nor could they readily understand the new theories. The theoretical men, on the other hand, were of little assistance to them, because their knowledge, being of a general nature, was not in a condition to be applied.

It is here that we find theory and practice clashing. Craftsmen laughed at the new fangled theories which would not work in practice, and the theorists were handicapped because mechanics could not make special application of general principles.

It is evident that the above conditions demanded a com-

bination of the qualities of the theorists or physicists and mechanic, *i. e.*, technically educated engineers.

Because of the above demands the technical college developed from the scientific, just as the scientific had already branched off from the classical. Then there arose the question as to just how much practical work should be given the student. Four years had long since become the regulation length of a college course, and if there was any tendency to change it was to shorten rather than to lengthen the time. It had already been necessary to strike out many of the so-called culture studies from the curriculum to make room for the technical; and the latter having been introduced, it was necessary, in order to teach practice, either to reduce the time put on theoretical instruction, or to cut out more of the culture studies, such as languages, history, etc. Some colleges went so far, as to offer courses in which nothing was taught but shop work and strictly engineering subjects. This simply amounted to a quick way of learning a trade. Such courses, however, have been dropped in most cases because it was found that graduates either pursued the trade thus learned, which they could perhaps better have acquired as apprentices, or else they took enough more work to complete the regular four year course.

The question of relative amounts of time to be put in the laboratory or shop and in the class-room was, and still is unsettled, and practice varies somewhat in the different engineering schools.

The Electrical Department of the University of Minnesota does not aim to teach trades, but rather to turn out men who are well grounded in theory. Practice, which is but the continued application of the same principles, can be best obtained outside of college. Theory cannot be taught anywhere else to better advantage than in school. (It may be remarked parenthetically, that all engineering students are advised to use their summer vacations to the best possible advantage in securing experience along their special lines. Students who are backward in the application of theories are sometimes advised to stay out of school a year for the same purpose) Sufficient laboratory work is given,

therefore, to clinch the theory, working on the idea that from an engineer's standpoint what one does not know how to apply he does not know at all.

It is now seen that when we say we give just enough laboratory work to enable the average student to master the maximum amount of theory, that we do not mean by "Theoretical Man" one who knows a great deal but can apply little, but rather we mean a man who knows the fundamental principles and can apply them and who knows that he can. Practice will, of course, make him more proficient. To illustrate--we have no hesitation whatever to recommend many of our electrical students to take charge of electric power-houses and the like immediately on graduation. Many of them have done it with success and others have taken positions of responsibility in other branches of electrical engineering.

When it is learned that students are thus fitted with an aggregate of only 300 hours ol electrical laboratory instruction, most practical men may hesitate tocredit the graduate with much knowledge and will probably be interested to know something in detail of the electrical laboratory methods used at the University of Minnesota.

To start with it will not be contended that the student has learned most of what he knows in the laboratory; on the contrary, notwithstanding the fact that shops and laboratorles are indispensible to an engineering college, the bulk of a technical training is acquired in the class and lecture room.

During the first two years the work is the same as in other regular college courses, with a leaning toward the sciences. The student acquires a good general education, learns many fundamental principles, most of which he applies in some prescribed way such as problems and outlined laboratory experiments. He is especially well grounded in physics and mathematics. The subject of Mechanics is studied during all three terms of the third year. Physics is continued in lecture class and laboratory the first two terms of the same year.

In the second term of the third year, there is a course of

lectures on industrial electricity, treating of its application, the use and abuse of instruments, and generally outlining the technical work to follow.

In the third term of the third year the subject of Dynamo and Electric Machinery is taken up four times a week in the class room, using S. P. Thompsons' text-book which is supplemented by lectures and by reference to other books on the same subject. This is accompanied by a corresponding course of ten hours a week in the electrical laboratory, which is the first work that is similar in any way to commercial electrical engineering.

As the methods used in this course depend somewhat on the preparation received in the previous two terms of physical laboratory, it will be well to outline the latter.

Out of a total of 46 experiments, requiring in the aggregate 80 hours in the laboratory, the following are selected to indicate the nature of the course:

Determination of "H" by two methods. Tangent galvanometer. Calibration of ammeter and potential galvanometer. Determination of absolute resistance and electromotiveforce, calorimeter method. Resistance and potential problems. Work. Efficiency. Magnetic properties of iron, B., "mu.," etc. Ballistic galvanometer. Determination of capacity of a condenser. Coefficients of induction.

On finishing the above, the student has acquired a a thorough understanding of the theory of electric measurements, an acquaintance with the construction, adjustment and care of delicate electrical instruments, has learned how to take observations, keep notes, and to calculate limits of error.

While correct manipulation is necessary to produce accurate results, which are insisted upon, a thorough understanding of the fundamental principles is held paramount.

Thus, after preparation extending over a period of nearly three years, the student has yet to acquire that special knowledge and training which will entitle him to the degree of Electrical Engineer.

As has already been stated, his practical electrical experience begins with 120 hours (M. E. students take 72) in the third term of the third year, and briefly is as follows:

(1) About two weeks, or 20 hours, are spent in getting acquainted with the electricial laboratory by tracing and making diagrammatic sketches of the circuits of the switchboards, room wiring, storage battery plant, and machines. Different methods, as found necessary, are used in locating the circuits, such as: by sight, pulling the wires, magneto, incandescent lamp, voltmeter, and compass, while concealed wires are found by the use of the telephone and exploring coil.

(2). Soldering, splicing wire, and wiring.

(3). General care of dynamo electric machinery, setting brushes, sand papering commutators, oils and filters, and trimming arc lamps.

(4). Experimenting with the electric arc using a magnet, compass, and lens.

(5). Construction of an ammeter and voltmeter from a galvanometer.

(6). Calibration of an ammeter and voltmeter.

(7). Test of fuse wires.

(8). Insulation testing, (a) with high resistance voltmeter, (b) with bridge.

(9). Study of a dynamo or motor.

(A). Measurement of the resistance of the amature and field coils (a) by use of ammeter and voltmeter, (b) by use of bridge.

(B). Circular mils per ampere in coils, etc.

(C). Sketch of the magnetic circuit.

(D.) Determination of the magnetic leakage co-efficient for different field excitations by the ballistic galvanometer and temporary coil method.

(E.) (a) Operation as a dynamo and as a motor, regulation, effect of shifting the brushes, etc. (b) Running as a motor with the field excited by the armature only.

(10). Potential curves around the commutator, showing the distribution of the magnetic field.

(11) Application of the fundamental equation $E = \frac{NZn}{10^8}$, to a dynamo and to a motor, to find "N" and "Z" where only the outside layer of the armature winding can be counted.

(12) Magnetization curves of a dynamo or motor.

(13) Determination of the series turns and size of wire necessary to compound a shunt dynamo for a certain per cent rise in voltage at maximum load.

(14) Application of the fundamental equation $f = \frac{Hcl}{10}$. Given the machine used in exp. (9), to compute the TORQUE under certain conditions and to prove by experiment.

(15) Application of the fundamental equation of the magnetic circuit $N = \frac{\frac{4\pi Sc}{10}}{\lesssim \frac{l}{A\mu}}$ Given a machine to find the ampere-turns for different parts of the magnetic circuit.

(16) Primary and secondary cells, care of, charging and discharging, measurement of the internal resistance, and time tests with curves showing current, voltage, etc.

(17) The principal characteristic curves of a (a) shunt dynamo, (b) series dynamo and (c) compound dynamo.

(18) Characteristic curves of arc dynamos; constant-current and constant-potential arc lamps.

(19) Three wire distribution experiment.

(20) Primary calibration of ammeters and volt-meters, using the potentiometer and standard resistances and cells. Watt-meter calibration.

(21) Electrical and commercial efficiency curves of a dynamo or motor, separation of all losses, use of the prony

brake and cradle dynamometer, and determination of the best speed.

(22) Temperature, time, resistance and current test of coils.

(23) Static and gyrostatic balance of armatures.

(24) Station operating.

LABORATORY METHODS.

The theory is given first in class. To illustrate, take experiment (11): The equation $E = \frac{NZn}{10^8}$ and its application to dynamos and motors are discussed and explained in the classroom. A problem is then given in which "N" is the unknown quantity. As soon as possible after this, generally not more than a week, the experiment is taken up in the laboratory.

There is in almost every experiment a definite numerical result to be obtained. As accurate results are insisted upon and instruments used are checked in some way before and after the experiment, the student soon learns that success depends entirely on his own persistant and careful efforts. Having once learned this his work begins to count and he will accomplish more alone than otherwise and with an instructor at his elbow. If he cannot learn to feel his own strength, he will never start an experiment with any other idea than that he may perhaps get a result, which would be ruinous to all prospects of success. Such a student would soon be spending half his time finding excuses for what he had done the other half.

An instrument which does not agree with itself within a small known limit of error is unfit to be used by students. Nothing will more effectively prevent fudging and guessing and will instill a regard for at least the technical truth than will the use of accurate instruments and the demands for accurate results. Poor instruments, poor methods and an instructor who anticipates every new idea and danger, will spoil the best of students.

With good instruments and good methods, most students will do better in the long run if allowed to use their own judgment as to when they need assistance. And in fact, if allowed to think for themselves at the beginning they soon learn to enjoy using their own judgment, and will not seek help until actually cornered, and even then sometimes obtain the desired information from a fellow student. This is well, because where the advice of an instructor would be accepted without question, that of a fellow student is carefully considered before being utilized.

Some students have difficulty in losing the primary school idea that their every move is watched and that if about to make a false step, they will be warned in some providential manner in time to save themselves and instruments. In work where not only instruments but even life itself must be entrusted to the memory, such helplessness is absolutely dangerous, for there is often nothing about a conductor to indicate whether it is charged or not, and pressure as high as 40000 volts is used for experimental purposes in the electrical laboratory of the University of Minnesota. It must not be thought, however, that such dangerous pressures are permitted to be used by beginners. On the contrary, the above statement is made to show the necessity of a students developing, as soon as possible, a capacity for independent action, an appreciation of responsibility, good judgment and correct habits. He gets the first by acting independently, the second by being responsible, good judgment comes only from using judgment, and correct habits from the repeated use of proper methods.

It is sometimes necessary to frankly tell students that they are not watched, and leave them alone with the understanding that results will tell the whole story. This method sometimes costs the department the repair of an instrument in the early part of a students' career, but is, no doubt, a saving in the end, because once a student has learned that it is his own head, and not some unseen hand, which keeps him out of trouble, he seldom has any difficulty.

The prescribed list of experiments is followed only so far

as one naturally leads up to another. Experiments are selected to fit the needs of different students, who are encouraged to devise new ones for themselves. Shop and tools, as well as the regular laboratory instruments, are placed at their disposal at all times. The laboratory is regularly open afternoons between two and six, yet experimenters can be found there any time between 7:30 mornings and 2 at night. It is endeavored as far as possible, to have the ten hours a week put in, in consecutive four hour periods, as it is found that the less the time is broken up, the more work can be done.

Every student keeps in a note book, a complete account of all experiments undertaken, which book is turned in at the end of the term, and together with the time, and general character of the work done in the laboratory, furnishes the basis of marking and grading.

It might be supposed where full leeway is given, and no restriction placed on the amount of work done, within reasonable limits, that the students would soon be of all sorts of grades. This is the case, of course, to an extent but really is not objectionable, because extra work done is the individual's own gain.

A condition which tends to increase the amount accomplished by the poorer students, is that the best men as a rule do not object at all to having as laboratory partners, the poorest men. While in one way, this is not a good arrangement for the weak student, since his partner does most of the headwork, yet, inasmuch as it keeps him up with the class, and gives him an opportunity to clinch the theory as soon as it is learned, it is probably the best that can be done, for the required number of experiments cannot be limited to what the poorest man can do working alone. Another way of making the grade uniform, and one which is usually agreeable to the students, is for those who have had practical experience to select as partners those who have not had the same opportunities.

Experiment N. 24, Station Operating, is usually done outside of regular laboratory time and consists in running the dynamos to furnish extra lights for University evening af-

fairs. For this the students are sometimes paid, which also is the case with wiring, those who can do such work being given the preference over outside help.

As the space allotted to this article is already filled it will be necessary to close with a brief accounting of the remaining 180 hours. Seventy hours are given respectively to the first and second terms of the senior year. The first term's work is on Alternating Currents and that of the second on Alternating Currents and Photometry, Arc Lights and Incandescent Lights. The remaining 40 hours are taken up by Plant Operation in the second term of the senior year, operating the university lighting plant under the direction of the regular engineer.

The same general plan is followed fhroughout, the theory being first taken up in class or lecture room and then followed immediately by an experimental demonstration in the laboratory.

THE "BOSTON AND MONTANA" SYSTEM OF SURVEYING.

P. B. MCINTOSH, E. M. '98.

The system of surveying and recording surveying notes used by the "Boston and Montana Consolidated Copper and Silver Mining Company" of Butte, Montana, is the product of twenty-five years experience in this department of mining work. The system was devised and perfected by Mr. C. C. Batterman, a graduate of the mining department of the University of California, in the early convention. Mr. Batterman, now mine superintendent of the Boston and Montana Company, has been closely connected with the development of the mining industry in Colorado and Montana during its period of greatest activity.

A glance at a mining map of one of the western mining districts, like the "Summit Valley" or Butte district, will convince the engineer that some very complete and accurate method of surveying and recording surveying notes is necessary to prevent complications. The industry in these states is carried on under the provision of the "United States Mining Laws." The land of the district being divided up into "Claims" 1,500 x 300 feet, or fractions thereof. These claims were located by the early prospectors and the corners were marked by stones on which were marked the number of the lot and corner of the claim. These numerous claims overlap each other in every conceivable way and the corner stones are easily moved or destroyed. It is therefore essential that at the beginning of active development work these corners should be surveyed and accurate records kept for future reference.

Again, when the mine has become a producer, the exact location of the underground workings with respect to the old end lines to the claim is necessary. A matter of a few tenths of a foot beyond the line, when following a rich vein

may cause considerable trouble and expense to the mining company.

A point is taken on some prominent piece of ground within the limits of the property of the company and is marked by an iron pin driven into the ground. A brass tag bearing the number of this point or station, is nailed to a stump or on a stake near by. Co-ordinates are assumed for this station, for example: 5,000 feet north, and 5,000 feet east. These numbers are taken so that all points on the property shall then be north and east of the imaginary base. Another station is located either north or south of the first station, and the true north and south line thus established. This may be called the working base. Other stations are established at different points on the surface, and their position with respect to the working base determined by triangulation.

From these triangulation points, other stations are put in. These are so situated, that the distance between the transit and the new station can be readily measured with a 300 foot tape. In this manner, permanent stations are located at many points on the surface, so that claim corners, buildings and shafts, can easily be located from them.

Measurements are made on the surface with a 300 foot steel tape, graduated to hundredths, and in measuring courses between stations and to important points, the inclined distance is taken with the vertical angle.

The field books used, are leather bound, 5x7½ inches, and the pages are numbered consecutively through a whole series. The first, containing pages from 1 to 100, and the next from 100 to 200.

This method of numbering the pages of the field books, is found to save much trouble. On the left side of the page are columns for the following notes: station and backsight, height of instruments, angle, compass, vertical angle and inclined distance, and on the right side, one column for the horizontal distance, and the remaining space for remarks and sketches.

Each station, whether on surface or under ground, is

FIG. 1.

PAGE OF COMPUTATION BOOK.

MEADERVILLE SURFACE.

August 12th, 1898.

NOTE BOOK 2047.

Sta. 437 to 1524								
Az. =	137° 27′							
Angle +	197° 12′						North	East
	334° 39′						2946.52	6237.46
B. S. 437° —	180°				Cos.	Sin.	— 212.62	+ 102.44
Sta. 1524	154° 39′	S 25° 21′	E 239.26′ to Sta. 1525		212 62	102.44	2733.90 (1525)	6339.90

marked by a brass tag, bearing the number of the station.

After the field notes have been taken and explanatory sketches made, the engineer goes with his assistant to the office where the computing and recording of the notes are done. Regular computation books are kept on hand, and every engineer has his own book. These contain good pencil paper and are about 10x13 inches in size. They are also numbered consecutively; the first book containing pages from 1 to 1,000, and the next from 1,000 to 2,000. All computations are made by the engineer and assistant at the same time, and the results checked. First, the inclined distances are reduced to horizontal and vertical distances, and these obtaining the latitudes and departures of the courses, are entered in the field book. R. L. Gurden's traverse tables are used. After the horizontal distances have been obtained, the co-ordinates of the stations are computed in the usual manner.

The number of the page of the field book from which the notes are taken, is entered in the computation book, and the number of the page of the computation book is likewise noted in the field book.

When the work has been computed by the engineer and assistant, and checked throughout, it is entered in ink in a specially prepared book called the ledger. Each mine of the company has a ledger, and this is divided into sections, for the different levels, and subdivided for the notes of the different drifts and crosscuts. The ledger is provided with an index, so the engineer is enabled to turn to the notes of any part of the mine at a moments notice. The ledger is made of good paper and well bound. Size 11x14 inches. Each book contains one hundred pages arranged similiarly to the pages of the field book. The arrangement of the notes in the ledger can be best understood by referring to the sample page figure two. The second column marked X is for the height of instrument, which, in surface work is plus, and in underground work generally minus. The angular reading is taken twice; then if the readings do not check, the process is repeated. Both the single and double readings are entered in the ledger. The compass reading

FIG. 2.

SURFACE SURVEY CONTINUED.

1614

Abbott & Davis.
Aug. 9th, 1898.

Station	(+)	Ang.R.	Azimuth	Compass	Ver. Ang.	Slope Dis.	Ver. Dis.	Cor. Bearing	Distance	L. N.
1524 B. S. 437	+4.27	197° 12′ 394° 24′	154° 39′	S. 24° E.	— 2° 11′	239.43	9.12	S. 25° 21′ E.	239.26	.....

CONTINUED. 1614

L. S.	D. H.	D. W.	O. N.	O. S.	O. E.	O. W.	H. P.	H. F.	Elevation		Page
312.62	102.44	.....	2733.90	.....	6339.90	.....	.....	....	.....	to Sta. 1525 Iron pin near N. W. corner of "Bulley Boy."	2047

Sample Page of Ledger.

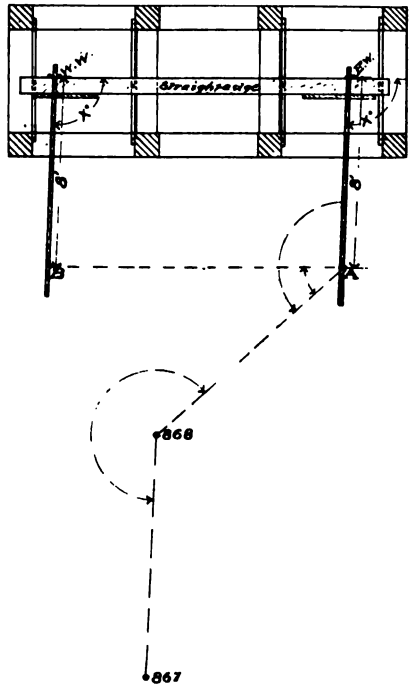
is taken for each course and serves for a check to the connected bearing.

PLUMBING THE SHAFT.

Now that the important points on the surface have been surveyed and co-ordinates of the stations and azimuths of the courses computed and entered in the ledger, the engineer is called upon to locate the underground workings. Two fine wires are suspended in the shaft, one at each end, and to these are fastened heavy weights which are allowed to hang in a bucket of water or oil. The shaft in this case is vertical and the wires extend as far down as it is necessary to carry the survey.

FIG. 8

ARRANGEMENT AT SURFACE



A straight-edge, made of an inch board about eight inches wide and long enough to extend from one end of the shaft to the other, is prepared. Four pieces of 2 x 2 are nailed to the studdles crosswise of the shaft and about two feet above the floor. The long straight-edge is placed on these horizontal strips, brought to within about $\frac{1}{16}$ inch to the wire on each end, and securely nailed. Two adjustable "T" squares are also prepaired. These are made of 2 x 1 inch pine with a thumb screw clamp. The length of the long arm should be about 10 feet and the cross piece three or four feet. The cross arm being attached about one foot from the end of the long arm. By placing the two together, and tightening the clamps, the angles of the one are made equal to the angles of the other. They should be about 90 feet. The projecting end of the long arm of the "T" square is brought to within about $\frac{1}{16}$ inch of the wire, the short arm is pressed firmly to the outer edge of the straight-edge and the long arm is blocked up to a horizontal position. Each "T" square is then clamped to the straight edge. An equal distance (about 8 feet) is measured off from each wire on the long arm. See Fig. 3.

The two stations, 868 and 867, have been previously located. The transit is now set up at station 868 and angle 867—868—A determined; then it is moved to point A and angle 868—A—B and 868—A—B. W. read. The courses being measured the engineer has sufficient data to determine the co-ordinate of the (E. W.) and the azimuth of the line joining the two wires. The course A—B is calculated and is the same as the course E. W.—W. W. The "T" square and straight-edge are now removed and placed in a like position at the level below. The distance between the wires is measured at the surface and at each level to make sure that they have not come in contact with objecfs in the shaft. The distance between the points on the "T" squares, equal distance from the wires is also measured and should be the same as the distance betweeu the wires. The "T" squares are placed so that the transit can be set up at a convenient point on either side of the shaft. At the level we have the co-ordinates of the East wire (E. W.) known and also the

azimuth of course A—B′. This being the same as the course E. W.—W. W. The angle E. W.—A′—B′ is read, also the angle to the new station No. 1526. Another station 1527 is put up and angle A′—1526—1527 determined.

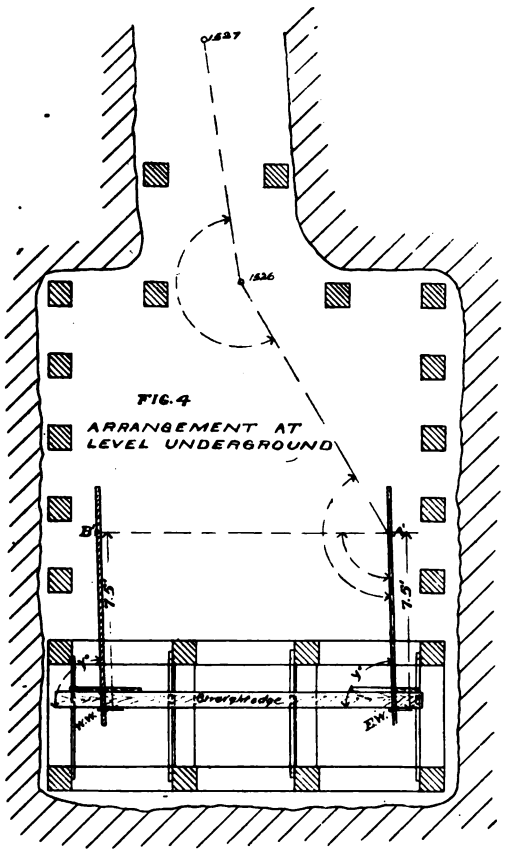


FIG. 4
ARRANGEMENT AT LEVEL UNDERGROUND

As the angle to each underground station is read the horizontal distance is measured; also the heights of instrument, heighth of point (H. P.) and heigth of floor (H. F.)

The underground survey notes are computed and entered in the ledger in the same way as the surface notes shown above; the column headed H. P., H. F., and elevation being also filled in.

ENGINEERING AND FINANCE.

MORGAN BROOKS.

With the return of prosperity, we may expect a great increase in engineering undertakings, with the consequent increase in the demand for competent engineers. The rate of interest paid by borrower's in good credit was never before so low in the United States. Securities of undoubted value were never so high in price. A perfectly safe investment brings a return of but three per cent. Capital is anxious to find an opening where five per cent. is assured, hence, enterprises of substantial merit can readily find capital. Owing to the reckless promotion of questionable electrical schemes in the past, it may be more difficult to convince investors of the worth of enterprises in the electrical field, than in other engineering lines; and our graduating engineers should realize their responsibility by refusing to countenance any merely speculative scheme. A lawyer may sometimes espouse a questionable cause, knowing that his opponent will present the other side, but an engineer should never sanction what he cannot approve. He should give advice with scrupulous honesty, making his estimates neither above nor below what his best judgment would indicate. A too-conservatuve estimate of profits, may discourage a profitable undertaking, whereas exaggeration will certainly bring disappointment.

Foreign critics have often pointed out our inflammable railway bridges and dangerous trolley lines as evidence of lack of engineering ability in America. Rather are they evidence of the ability of our engineers to overcome obstacles with inexpensive construction. Recent changes in financial conditions will give our engineers the means to rival their foreign brethren in executing works of the most substantial character. The current rate of in-

terest in New York being now as low as that of London, engineering methods can be more properly compared.

The financial method of valuing property in proportion to its earning capacity may well be applied to many engineering projects. If a street railway or an electric power plant earns $4,000 above all proper charges for operating, maintenance and depreciation it may fairly be valued at $100,000, even if it cost but half that sum. The franchise may be considered to represent the difference. An exception must be made in the event of competition being possible, since in that case a portion of the business may be lost, even if there be no reduction of rates. In an engineering project, a rough estimate of the earning capacity of the proposed plant may serve to show that under no probable conditions could the project become a paying investment; hence such estimate of earnings might save much valuable time in making detailed plans and specifications, if the more methodical order of procedure be followed. For example, as an engineering undertaking, the laying of a telegraph cable to the Hawaiian Islands could not receive favorable consideration, its probable volume of business not warranting it. Nevertheless as a military necessity our government might be willing to grant a sufficient subsidy to make it a paying investment. In this way the first transcontinental railroad was built.

Although the rate of interest has fallen the proper allowance for depreciation has probably increased in dynamic engineering. The rapidity with which new inventions have been introduced has made machinery of almost every description out-of-date long before it is worn out. The proper time to discard out-of-date machinery is a different question. You have all heard of the "Smashing point" of incandescent lamps. That point can be quite easily calculated, because we can be reasonably sure of our premises, and hence of our conclusions. In the case of inefficient machinery, while a change may be clearly indicated as a business proposition, we may feel that in the natural progress of events still greater improvements may be expected, and we hesitate to demand a much needed improvement. If im-

proved apparatus would cause a definite saving, that saving may be capitalized, and the possible amount of money safely to be expended determined.

After allowing for all repairs it has often been the practice to consider that an allowance of 5 per cent. for depreciation is sufficient. It seems to me that this should be increased to ten per cent. Even at ten per cent it takes seven and one half years to reduce the investment to half its original value, since it is always the practice to deduct the percentage of depreciation from the balance, the successive deductions becoming smaller,—a sort of negative compound interest. Upon this basis an improvement which produces a saving of $1,000 annually would justify an investment not exceeding $7,000, since an allowance of ten per cent for depreciation and four per cent. for interest falls within the $1,000.

By the same method labor-saving devices may be capital ized, such for example, as a mechanical stoker. However the situation may be viewed broadly, to make sure that in no other way could the money to be appropriated for such purpose be more advantageously expended. In making such inquiry all the knowledge and experience of the engineer are demanded.

It should be remembered that the element of depreciation may not always exist in an engineering problem. Take the selection of a location for an electric central station. The investment in land for the power house should not be subject to depreciating influences. Considering alone the interest at four per cent. on the value of the land, saving of line losses to the extent of four per cent. would warrant an increased expenditure for a more centrally located lot of any amount up to the entire annual fuel bill of that plant, provided the more expensive location did not entail other expenses, such as extra cost in hauling fuel.

The necessity of keeping pace with improvements is not always appreciated. A lighting plant may be earning good dividends in spite of the the continued use of inefficient machinery, and the directors may rest in unwarranted

security. Such a condition may attract competition from capitalists who are willing to install the most improved apparatus, and who could then afford to reduce rates below these essential to the continued existence of the older company.

The secret of success in any business lies in keeping operating expenses (including depreciation and fixed charges) within income, so as to leave a margin of profit. This is not always accomplished best by paying the lowest wages. A poor mechanic invariably spoils enough good material to pay the difference in wages required by a competant man. Moreover an underpaid man is apt not to regard his employer's best interests. Oftentimes a very slight improvement in the operating condition of a plant turns loss into gain.

Unless a plant can show a profit or a reasonable expectation of profit in the near future, it should be closed at once, and the machinery sold. No effort should be spared in bettering the prospects of a decadent plant. Such suggestions as that of utilizing surplus power at light load hours for such work as the manufacture of artificial ice; are to be commended. It is idle to await "better times." If conditions are unsatisfactory change *them*. Energy of management is quite as important as the energy of steam. The American engineer, with his fund of resource, has been able to make marvelous progress with comparatively little capital. Now that the conditions of our country's finances permit greater expenditure and more substantial construction, let us accept the responsibility, and lead the world in true economical engineering.

WATER WORKS FOR SMALL CITIES AND TOWNS.

C. F. LOWETH.

It is my purpose to talk to you of some practical considerations in connection with the construction of water-works for the smaller cities, and to illustrate these remarks by some examples of work as actually built. We will not enter into theoretical considerations.

Generally a municipal water works plant is for the purpose of furnishing a suitable and sufficient supply of water, for all purposes required by a community; for all domestic purposes, as drinking, cooking, laundry, and other household uses; for domestic animals, garden, lawn, and street sprinkling; for manufacturing purposes and use in steam boilers; and last, but by no means least, for the extinguishment of fires or fire protection.

The supply should be alike amply sufficient in quantity and of proper quality for all of these purposes. Generally, the requirements for fire protection will determine the quantity required and the size of the works throughout, while the requirements for domestic and manufacturing uses will determine the quality of the supply. It is not infrequently a difficult matter to find a supply sufficient in quantity, and of suitable quality.

QUALITY.—Until lately many of the smaller cities have built water works principally for the purpose of fire protection, and with no thought that the water would be used to any great extent, if at all, for domestic purposes, and consequently the prime consideration was the sufficiency of the supply. Experience shows that the use of public water supplies for all purposes, domestic as well as others, has been steadily increasing, and at the same time there has been a constantly increasing pollution of many of the streams and other sources of water supply; both of these

have made it necessary for many cities to seek new sources of water supply, or to add filtering plants. In the design of new works it is necessary that a supply of unquestioned purity, in a sanitary sense, be selected. Modern science has proven that some diseases are propagated to a large extent, by water bourn germs; typhoid fever especially, some, even contending that it is only propagated through water, though this may be questioned.

It is possible by continued storage, and the resulting sedimentation of the water or some process of filtration, natural or mechanical, to make a seriously polluted water perfectly safe, but these should only be considered as last resorts. They involve large items of first cost, as also of expense of operation and maintenance, and there remains the possibility of reasonable doubt whether by lack of proper and intelligent care they may not occasionally prove inefficient. Mr. Allen Hazen, late chemist to the Massachusetts State Board of Health, has well said, "The main point is that disease-germs shall not be present in our drinking water. If they can be kept out in the first place at reasonable expense, that is the thing to do. Innocense is better than repentance. If they cannot be kept out, we must take them out afterwards; it does not matter how this is done, so long as the work is thorough."

Rivers and lakes are unsuitable for municipal water supplies unless the water sheds are but sparcely populated. Shallow wells are unsuitable if the flow reaching them is through a subsoil underlaying a populated area. Deep or artesian wells generallyfurnish a pure water in a sanitary sense, though often objectionable on account of hardness, and are not infrequently absolutely unfit for cooking, laundry and manufacturing purposes, because of high mineral properties. (Remarks St. James and Marshall, Jamestown, N. D.) Any supply should, if possible, be traced to its ultimate source in order to discover any probability of pollution, and in addtion chemical or bacteriological analyses, one or both, should be made and intelligently interrupted. (Note chlorine.)

The water from deep or artesion wells will generally have

been a longer time in flowing from its surface gathering grounds, than is the lifetime of any harmful bacteria, which it may have originally contained. There may be, however, exceptions to this, and water from such wells be seriously polluted, as in the case of artesian wells not far to the southward of St. Paul and Minneapolis, and where the supply is from the sandrock stratum, underlying and cropping out within these two cities, aud in which many sewers and cess pools are built. The deepest waters are generally the hardest and most highly mineral, due to the longer time the solvent property of the water has had in which to act on the material through which it flowed.

CAPACITY OF WORKS.

The requisite capacity of the works will vary, of course, with the size of the city, and in addition with the characteristics of the locality. As the quality of the water is more or less desirable, it will be more or less used for domestic purposes; if wells for private use are cheaply gotten, and the water of good quality, a public supply will much more slowly come into general use than if otherwise. A well suitable for family use may cost in one place $10 or less, and in another $100 or more. In some communities a public water supply will be more quickly appreciated and made use of.

The quantity of water likely to be used for manufacturing purposes is very variable. Some manufacturing industries require no water except for boiler use, and not then if operated by water power, while others require considerable. Many manufacturers find it to their interest to obtain their own supply rather than to patronize that of the city. Some cities sell large quantities of water to the railroads, especially where the water is of good quality; in some cases this use of water approximates the amount used for all other purposes.

The larger cities of this country are now using water at the rate of 75 to 200 or more gallons per capita per day, this being the use for all purposes. This is much in excess of the actual necessary and legitimate requirements, and

much exceeds the amounts used in Europe, and is doubtless largely due to wilful and negligent waste. The consumption per capita has been steadily on the increase, but probably will not so continue in the future. It is possible by several means to restrict to a large extent the excessive use and waste of water, and because it will be cheaper to provide the means and enforce such regulations as will accomplish this than to furnish more liberal supplies, it will undoubtedly be done. In some cases this is nearly the only alternative.

The smaller cities will probably never make as general use of a public water supply as do the larger ones, and the requirements per capita will be less; and it would seem that waste could likely be better kept in check. Fifty to 100 gallons per capita daily would seem an ample supply, varying according to the conditions, and making reasonable provision for increase of population.

It should be remembered that in any case the general use of the city water will come gradually, and the design of the works should be such as will admit of growth and enlargement, as may later become necessary, and without involving changes other than those incidental to additions and extensions. This would be a measure of wise economy in any case, but is nearly always absolutely imperative for the reason that financial ability rarely if ever permits of the construction of a thoroughly complete plant, proportioned throughout for future requirements. On this account many plants, some of which have been in use for five or more years, are now being operated with but one pump, as at Faribault and Red Wing, though at the latter place an additional pump is now being installed.

In the larger cities the quantity of water used for fire protection is small in comparison with that used for all other purposes; but not so in the smaller towns, where the requirements for fire protection will quite likely determine the size of the plant throughout; even in the larger plants it will be necessary to observe whether such locality can be supplied with the number and size of fire streams which the character of its improvements demands.

Efficient fire protection will vary from four to twenty or

more fire streams, each of 150 to 250 or more gallons per minute, depending upon the size of the city and the character of its improvements, and varying for the different sections of the city.

Let us pass now to the practical methods of gathering the supply. Rivers and lakes are the most desirable in this respect. There is usually no question as to the abundance of the supply, and but comparatively little expense is required for collecting works. An intake pipe can be extended into the river or lake at small cost, and it is only necessary to guard against it being covered up or obstructed by deposits of silt, etc., or destruction or stoppage by floods, driftwood, and floating or anchor ice. A suitable strainer must also be provided. All of these are generally details of no great difficulty.

Shallow open wells can quite frequently be obtained, which will furnish large quantities of water; they are comparatively cheap and easy of construction. They are generally built with masonry walls on wooden or iron curbs, and most frequently the curbs with the wells are sunk by excavating under the curb. They should be covered with a light frame roof.

Tubular wells are frequently used, especially where the water bearing strata is too deep to be easily or economically reached by open wells or galleries. Such wells are usually of small diameter, two or three inches more or less, the well points with strainers being driven into the water bearing strata, and all connected to a common main pipe leading to the pump. This usually involves a long suction pipe from the pump, with many joints and connections, more or less difficult to keep air tight, and a leaky suction pipe results inefficient pumping and much annoyance, and if the water contains much gas, as sometimes occurs, the trouble is much increased.

For this reason, we have avoided wherever possible, the use of tubular wells, preferring some other plan where the suction pipe connected with the pump can be made of short length, and be readily accessible for examination. Brooklyn, N. Y. obtains a large proportion of its water

supply from tubular wells. Sioux City, Iowa, obtains its entire supply by such means, and from two pumping tations each with its own system of tubular wells. Detroit and Litchfield, this state, both obtain their supplies by this means.

As an alternative to their use we have on several occasions made a large open well, sinking tube wells in the bottom to a deeper water bearing strata, thus permitting the water to rise into the larger well, from which the pump takes its supply without being connected to the tube wells. This plan is possible only where the water bearing strata is of such thickness and so course as to permit of the tube wells being sunk close together, and where the water will rise nearly to the ground surface. (Cite Panora and Windom.) We have used a similar plan to reinforce an open well sunk into water bearing strata. For instance, at Lake City the supply was intended to be taken from a large open well sunk near Lake Pepin. We found that the flow during low water was insufficient and as the bottom of the well was in course gravel a number of large 4-inch tubular wells were sunk in the bottom of the larger well, which materially increased the supply.

Filter galleries which will furnish a large supply can be quite frequently obtained, especially in river valleys with extended sand or gravel strata. There is in many river valleys a large subsurface flow of water flowing down the valley and continually replenished by a subsurface flow from the higher ground on either side; this flow is more or less independent of that in the channel of the river, and is possible of course only in the case of an extended pervious strata. A filter gallery is simply an underground channel lying in this water bearing strata and intercepting the flow, which is led to a collecting well to which the suction of the pump is connected. Columbus, Ohio, and Des Moines, Ia., both obtain their entire supply by such means, the length of gallery in the latter city being at the present time about 4,100 feet in length.

It is well to bear in mind that the facility with which a supply can be obtained will depend upon the character of

the water bearing stratum. If the material is course, the voids are considerable and will hold a large amount of water and part with it freely; on the other hand fine sand has a small proportion of voids, holds much less water, and parts with it slowly.

Deep or artesian wells, from a constructive standpoint may be divided into two kinds, viz., flowing wells, in which the water rises above the surface and also those in which the water level rises within suction distance from the surface; and the other kind, those in which the water level is so far below the ground surface that it cannot be reached by a suction pump. The first class of wells are quite satisfactory in a constructive sense, as they admit of the use of ordinary pumping machinery, located entirely above ground, readily accessible for examination and repairs, and economical in cost both of construction and operation. With the second class of wells, special pumping machinery is required, which is expensive in first cost, operation and maintenance. The pump comunity consists of a steam cylinder, or a power driven working head, at the surface over the well, and connected by a long rod to a plunger working in the cylinder in the well and secured to a pipe extending to the surface,—allowing for thickness of cylinder, the valve seat and valve, there is little room left for water passages, and the arrangement is necessarily single acting, i. e., but one stroke or half of each complete revolution is effective in raising water. With one of these well cylinders, only 120 gallons per minute can be obtainod from a well with 8 inches inside diameter casing, and about 160 gallons with 10-inch casing, although the wells might furnish much more were the appliances more effectual. For this reason the well should be drilled of large diameter to such depth at which it will be necessary to place the pump cylinder. Again, these pump cylinders and their plungers are subject to considerable wear, and must often be taken out, more or less, a no small task. If the flow contains much sand it may settle down after pumping in such quantity as to prevent starting the pump again I believe the air lift pump will be generally pre-

ferable to the common form of deep well pump as above described; briefly it consists of two pipes in the well, the larger for the discharge, and the smaller for the air supply and having a goose neck turned up and into the lower end of the discharge pipe. Compressed air is forced through the smaller pipe, and escaping into the larger pipe, rises, bringing water with it, alternating by a plug of air and water. There are in the well no moving parts to become worn, displaced, or obstructed. The air compressing plant can be located at a distance from the well, and the same compressor can serve two or more wells located a considerable distance apart, while with the ordinary form of deep well pump one is needed for each well. Still another advantage is that the air lift pump will raise a much larger quantity of water than the other, thus in raising the yield from the well, and perhaps reducing the number required.

The pump cylinder, or the suction pipe of pump, as the case may be, should be low enough to insure a full supply at all times as sometimes these wells do not contrive to flow as strongly as at the first, and in others there is a marked seasonal fluctuation in the water level, as at Northfield, where a pressure gage in the engine room shows a pressure varying from 6 to 11 pounds.

In order that the well may not be unnecessarily deep and its cost thus increased, and that the water may rise as near the surface as possible, it should be located on as low ground as practicable, the boasted wisdom of some well-drillers notwithstanding.

The flow from the Northfield well brings up considerable fine sand. It was expected this would cease after the well had been in use a few months; it did not, however, and as the sand was cutting the pumps, and was otherwise undesirable, a sand-catcher was put in which has been quite successful in accomplishing all that the name implies.

In some instances, with any kind of well, it may be desirable to place the pump in a well pit, and while such an arrangement is obviously cumbersome, it may for several reasons, be fully justified. We have several times preferred this as the only alternative of a deep well pump. It is re-

ported that Mr. D. W. Mead, C. E., proposes in a plant now under construction at Rockford, Illinois, to place quite large pumps in pits about 60 feet deep, the steam ends being at the surface.

The Dakota's boast of water works where the artesian wells furnishes both the supply and power, no pumping plant being required, and Minnesota can claim nearly as much, as at Marshall, where I understand the flow from the well will fill the tower, which is about 100 feet high. As the rate of flow at this head is not entirely sufficient, a pumping plant is added; probably many of the Dakota wells are similarly weak. The maximum pressure of the well is not when it has the greatest flow; the pressure measured when the flow of the well is shut off, and the maximum free flow at the surface are not existing conditions.

Springs are rarely found with a sufficient volume of flow; we have in mind but two instances in our experience of a supply from such source, viz: Cedar Falls, Iowa; and Redwood Falls, Minnesota. In this latter case the ordinary supply is from the springs, but is insufficient for fire purposes, and the pumps are connected with the river, so that during fires, river water may be used as needed. Such an arrangement is quite common, but is permissible only when the auxiliary supply, while not desirable, is not positively dangerous.

MODE OF SUPPLY.

The mode of supply must be either by gravity or pumping. A gravity supply, i. e., one led to, and distributed through the city by force of gravity only, is of course preferable, because involving a minimum of expense for operation and attendance; but as the supply must generally come from some remote point, through long and costly conducts or aqueducts, it is very likely to prove quite expensive in cost of construction. The natural conditions essential for a gravity supply, are rarely met with in this central section of the United States.

There are two general plans where the supply is by pumping, viz: by direct pressure, and by reservoir.

In the direct pressure plan the supply is maintained en-

tirely by the constant operation of the pumps. The consumption of water varies daily and hourly, with a wide margin between the extremes. The pumping machinery must therefore be proportioned for the maximum and not the average rate of consumption; and in consequence, must for much of the time be worked at less than its rated and economical capacity. The attendance as also the consumption of fuel, must be constant. The machinery throughout must be at least in duplicate, as pumps, boilers, and their appurtenances are frequently out of service for repacking, cleaning, and minor repairs, to say nothing of occasional breakdowns, and reserve machinery must be ready for instant service at any such emergency.

The reservoir plan is that wherein the supply is maintained for all, or portions of the time, from a supply of water which has been stored in an elevated reservoir. By this plan the pumping is intermittent; it is discontinued when the reservoir is full, and resumed before it is emptied; the periods of pumping and their duration are in inverse proportion to the ratio of the reservoir capacity and the daily consumption of water. The intervals between pumping permit of making minor repairs, repacking and cleaning the pumps and boilers. With first class machinery properly designed for the conditions under which it is to be operated, and intelligently cared for, the liability of serious accidents which would interrupt the supply are remote, and except where great risks are involved, the duplication or reinforcement of the pumping plant may be, if necessary, a longer or shorter time deferred; in any event a less liberal reserve of power is required than in the direct pressure plan.

With intermittent pumping less pumping capacity is required, and often a less expensive grade of machinery is permissible; it can be operated at its most economical capacity, and constant attendance and fuel consumption is obviated.

A reservoir system may at times be operated as a direct pressure system. If the reservoir is not sufficiently elevated to produce efficient fire streams, or is too small to

maintain fire streams for a reasonable period, or is temporarily out of service, it can be shut off from the distribution mains and the supply be by direct pressure from the pumps.

There are several methods of cutting off the reservoir; those actuated automatically by the water pressure, or under the direct control of the engineer, are preferable. A swinging or butterfly valve or a float valve counter weighted, and so adjusted that the valve remains open under ordinary pressure, but closes with an increase of pressure, is frequently used. Any valve for this purpose must be so arranged as to close slowly, or serious water hammer is likely to result to the damage of pumping machinery or mains.

The advantages of the reservoir plan are so many and so important, that we consider it always the preferable plan, and it should be carried out to the fullest extent practicable. But the less the reservoir can be depended upon for all conditions of service, the less its advantages over the direct pressure system, and the greater care and attention required on this part of the water works officials, and the design of the entire plant must be governed accordingly.

RESERVOIRS.

The reservoir may be of earth or masonry on some nearby hill, or a water tower, or stand pipe. For reasons just stated the elevation should be such as will produce a in the street mains sufficient for all purposes, fire protection included. The location should be as nearly central to the distribution pipe system as practicable, so as to reduce the cost of main pipe, and also the friction losses in the pipe system to a minimum.

If not too large, they should be covered. Sub-surface waters will frequently deteriorate rapidly on exposure to sunlight.

The capacity should be as great as practicable; if possible a day's supply for all purposes, with some margin of surplus for emergencies, or an unusually large consumption.

For the purpose of illustration take a small town, where

a fire protection of four streams of 175 gallons each will suffice, and the daily consumption for other purposes will be, say 150,000 gallons, an average of 6,000 gallons hourly. If the reservoir capacity is 150,000 gallons, and is full at the outbreak of a fire, it will only stand the draught for three hours, and less if the fire occurs during the hours of maximum use of water. If one hour is a necessary allowance of time for getting up steam and pumping; then the reservoir should never be less than one-third full.

An earth or masonry reservoir is preferable if a suitable site can be gotten, and is cheaper than any form of artificially elevated reservoir of equal capacity. The cost of extra pipe line necessary to reach a distant elevated site, may frequently change the balance and make the other form of reservoir the cheapest, all things considered.

Reservoirs in the ground are generally part in excavation and part in embankment. The sides may be earth slopes, paved with concrete, brick, stone, or asphalt; or they may be vertical or nearly so, and of stone or brick. In any case they should be perfectly water tight, and if depending on the masonry wall for tightness, it should be thoroughly solid, with no unfilled joints.

Water tightness in a masonry wall requires more honest care and patience on the part of the mason than they are usually willing to bestow, and these are perhaps more essential than expert skill.

Water towers may be wood or metal tanks, elevated on wood, steel or masonry piers or towers. In this climate the inlet pipes must be protected from frost, and for small capacities the wooden tank is preferable on account of being more frost proof. The masonry tower is the best in appearance, and for moderate heights is the most desirable. The wood towers are of course least desirable and should only be used where the funds available will admit of nothing better. The cost of rebuilding these in ten or twelve years will be less than the saving in that time in the cost of operation as compared with a direct pressure system.

Standpipes, unless on elevated ground, have but little efficient reservoir capacity, as so large a proportion of their

contents is at too low an elevation to be of any but little service. Unless quite large, and full at the outbreak of a fire, they are of no practical value for fire service. They equalize the work of the pumping, by taking care of the fluctuations in the rate of consumption, and if the consumption is not too great will admit of intermittent pumping at frequent intervals, but when so used, thorough fire protection will require that the pumps be kept ready for instant use.

If standpipes are built on elevated ground then a larger portion, or even all of their contents become available, at least for the lower levels of the city.

Based on capacity only, they are cheaper than water towers, but considering efficiency in service the reverse is true. They are liable to injury from the ice which forms on the inside all around, and from top to bottom, which, in addition to being dangerous, materially reduces their capacity.

Where the supply is limited, as from a non flowing deep well, the storage or reservoir capacity must be large; and if elevated storage is too expensive, the cost may be reduced by providing part elevated storage and the other portion at the surface. At Waseca where the supply will not exceed about 225 gallons per minute, the storage comprises a tower of 100,000 gallons, and a 162,000 gallon steel reservoir on the surface. At Tracy, Minnesota, the supply from a deep well will not much exceed 150 gallons per minute, and the storage comprises a 100,000 gallon tower, and a masonry reservoir of about the same capacity. The work now under contract for construction at Glencoe, will be similar. In all three cases there is in addition to the deep well pump, a large fire pump, for raising the water from the surface reservoir. At St. James where the conditions were similar, we varied this plan as follows: an 18′x110′ standpipe, with a capacity of 190,000 gallons, was built and located near the well and pump house. The deep well pump raises the water into this standpipe. There is a large fire pump, having both its suction and discharge pipes connected with the main pipe from the standpipe in such manner as will admit of taking its supply from the standpipe and pumping direct

into the street mains. This arrangement makes the entire contents of the standpipe available for fire protection.

PIPE SYSTEMS.

In the construction of new works the funds available may not permit of a pipe system covering the entire city, but so much as may be laid at the beginning should be proportioned, not only for extensions within present improved and built up portions of the city, but for future growth of the city as well. All such provisions for the future must be wisely determined or the funds may not suffice to complete a plant large enough to be of much immediate benefit. It may in some cases be better to let the future, to some extent, take care of itself, than to design a plant on so extensive a plan that its operation will be a burden to the community, and because the pipe system is not expensive enough and so is able to earn but an insignificant revenue.

At the same time the pipe system can better be reduced than any other portion of the works if necessary to keep the cost of construction within limits. A pumping plant, building, or other structures, must generally be entirely completed to be of service, but the pipe system can be extended the following year from funds which may then be available.

The pipe system should first be so planned as to provide pipe protection for as large an area of the city as practicable, and so far as this will permit the pipe should be laid along such streets where the water supply would be made of the most immediate benefit, so as to insure as great a revenue as practicable from the beginning.

The size of the pipes must be proportioned throughout for the service required, bearing in mind that the requirements will vary from the character of each section of the city; fewer and less strong fire streams are required in the residence than in the business and manufacturing districts.

Dead ends are to be avoided wherever it can be easily done, but care must be exercised that this does not involve needless expense. They are objectionable because as good fire streams cannot be obtained as on circuits of the same size pips; in the latter case the water flows to the hydrants

from two directions and in the former from but one. Another objection to dead ends is their effect upon the quality of water; some waters will deteriorate rapidly if not in circulation. This is frequently the case with water from deep wells; this objection may be overcome by occasional flushings of the pipes through the hydrants, and if there are several consumers near the end of the pipe line they may use enough water to prevent trouble of this kind.

A pipe system may be likened to a tree which has its trunk, and large and small branches. If dead ends are avoided in construction they cannot be from time to time as the system is extended. Whenever an addition of a block or more of pipe is required, it cannot be expected to run around two, or perhaps three sides of a block, in order to obviate the dead end. It will frequently be cheaper to make the pipe larger than to put in unnecessary pipe for the purpose of making a circuit. Some margin in size should be allowed for, to provide for the deterioration of the inner surface of the pipe, or its filling up by sand or sediment, both of which will reduce the capacity. Cast iron pipe with lead and spigot joints is by all means preferable, and if well coated may be said to last indefinitely. Wrought iron pipe and the patented Kalimine pipe have not proven serviceable, and are now seldom used. Wooden pipe is now not much used. In an investigation at Cheboygan, Michigan, some time since, I found that wooden pipes which had been in service but a few years were leaking badly, especially under fire pressure, the trouble being decay at the joints and where the service connections had been made.

Hydrants should be located generally at each street intersection and in long blocks, and in important business districts more frequently. They should be provided with good drainage and be set deep enough so as to be below frost. Two sizes may be used, the larger in the central and more important portions of the city.

We have made it a practice as a rule to place the pipe line on the north and south sides of the street about 25 feet more or less from the street line, and to locate the hydrants always on the same corner with respect to the

points of the compass so as to be readily located. Valves are also placed as a rule on street lines, so as to be readily found. Valves are made to open either by turning to the right or to the left, and care should be taken that all valves in any system open by turning in the same direction. We have deemed it a good plan to use iron valve boxes over the valves, the cap of the box having on it in cast raised letters the word "open" with an arrow showing the direction in which to turn, as otherwise some valves would be closed when they should be open or the reverse.

It is important that the pipe system be made thoroughly tight throughout. This would not seem an impossible accomplishment, but unless care is taken, it will not be obtained. Here is another instance where considerable honest, patient care, as well as skill, is required of the workmen. The waste from a ⅛" or even a ⅓" orifice in 24 hours, and under high pressure, is considerable, and goes on from day to day, possibly getting worse. Leakage may occur from defective pipe, as sandholes, etc., or more likely from defective joints, or at valves and hydrants, and packing about the valve stand being a not infrequent point where leakage occurs.

Several years ago a contractor, upon completing a pipe line of about three miles in length, was very anxious to have this and his work accepted. The pipe line had been subject to a pressure test and found alright, but the test for tightness brought to light the fact that a storage capacity of 100,000 gallons was leaking away in about the space of eleven hours. All of the pipe line was in gravel with the subsoil 20 or more feet below the surface. Consequently, the leakage did not show at the surface as would have been the case under other conditions. To find the many leaks and correct them was a task of considerable difficulty, and much annoyance. A few house-connections had been made with the mains, and one of these was found very imperfectly made, and leaking to an extent perhaps equal to one-third of the total leakage.

I believe that the excessive use of water in many cities is due to leaky pipe systems. For several years we have re-

quired that a pipe system should not only be subject to a pressure test for determining its strength, but also to a test for tightness, and the specifications have set a permissible limit to the leakage with a penalty for all excess over that amount, the penalty being such as would make good to the city the cost of pumping the water wasted. The permissible leakage has been usually taken at 60 gallons per 24 hours per inch mile of pipe.

We now come to the pumping plant, which has already been referred to to some extent. All pumps for water works service should be strongly and substantially built as the service is usually severe and the consequences of breaks and resulting failures of the water supply would quite likely prove serious and costly. They should have large valve areas, especially through the suction valves. We have of late been specifying that the suction valves should equal from 50 to 60 per cent or more of the area of the plungers or pistons, and this valve area should preferably be made up of a large number of small valves rather than a few large valves. This matter of large valve area made up of many small valves, permits of higher speeds and smoother action than is otherwise practicable. There should be near the pump a water relief valve to guard against damage from water hammer, and where the pumps are likely to be used for direct pressure or pumping during fires, pump governors should be used.

The suction lifts should be as low and the suction pipes as short and direct as practicable, and these should be of ample size so that at maximum rate of pumping the velocity of the water through them will not exceed 200 feet per minute. Care should be exercised to make them air tight, the necessity of this largely increasing with the lift, and if these precautions are observed and the suction pipe is not too long and the lift too high, foot valves will not be required.

The kind of a pump to be installed will depend upon the character and extent of service, cost of fuel, etc. Generally, a high grade compound condensing pump will be the best, but the conditions of use, especially for the first few years,

will be such as will make these, little if any, more economical in service than a simpler and less expensive form of pump. Where the pumping is intermittent, the fuel expense for getting up steam, or for maintaining it between intervals of pumping, is a large per cent of the total cost of fuel, in some cases exceeding 50 per cent. We had recently to look into the fuel expense account for a city of about 3,000 inhabitants in this state, where the pumping machinery was such as would under proper conditions have developed a duty of exceeding 35,000,000 foot pounds, that is, would have developed power enough to have lifted over 35,000,000 pounds one foot high with 100 pounds of coal. The fuel account, averaged for an entire year, showed that the plant as a whole was developing a duty of but between 9 and 10 million foot pounds. The loss of efficiency in this case was due to conditions of service, management, and minor defects of the plant. For much of the year, steam was maintained continuously in one, and some times in two boilers, and a large proportion of the lack of efficiency was due to maintaining this steam pressure during the hours when the plant was not in actual operation.

For combined water and electric lighting plants, we have on several occasions used a power pump in preference to a common form of steam driven pump. The reason for this being that steam is generally more economically used in a steam engine than in a steam pump, the difference in efficiency being much greater than the loss in the transmission from engine to pump; and in addition, for a considerable portion of the time during which the lighting plant must necessarily be in operation, the load is not a maximum and there remains a surplus of power available for pumping, and if so used, the engine is run more nearly up to its rated and most economical loading. Such an arrangement is, of course, the most desirable where there is storage or reservoir capacity sufficient to permit of most if not all the pumping being done at night, while the lighting plant is in service.

Gasoline pumping plants have been used of late and with very good results, a gasoline engine being used to drive a

power or some other form of pump, either by belting or direct connection, the latter being preferable.

Finally, the most perplexing problem is often how to build well and perhaps but fairly efficiently with the funds available, which are always limited. The design most economical in the long run is seldom the cheapest in first cost; future requirements must to some extent be provided for, and what is done be well done, and our clients generally desire as much, or even more, than their older and richer neighbors. In this matter, perhaps more than in any other, there is occasion for skill, good judgment, and patient thought.

EDITORIAL.

The Engineers' Society has been favored this year with the most elaborate course of lectures that it has been their good fortunes to have. Mr. Wm. B. Snow, a man of widespread reputation, gave a lecture on the "Mechanical Draft," which was illustrated by steriоptican views. We were also favored by a lecture from a man of national reputation, Mr. J. J. Carty, who delivered an address on "Electrostatic Troubles on Telephone Lines." These, together with the other lectures, have been particularly appreciated by the students, who extended to each lecturer a hearty vote of thanks.

The proceedings of the Society have been bright this year in all but one particular. It has pleased God in his infinite wisdom to take from our midst Frank Scofield, a student respected and beloved by all who knew him and who's sudden departure from this earth has filled us all with sorrow. The feelings of the students were depicted in the flowral tributes modestly tendered at the time of his removal to his native town, Zumbrota.

The condition of membership of the society has been excellent this year except that more freshmen should have joined, and it is hoped that the membership committee will make strenuous efforts in this direction next fall. It is certainly of great advantage for freshmen to have the opportunity of attending these lectures, for they give to them an insight into the technicalities of engineering work, which would otherwise come only from experience and excessive reading. May next fall see the Engineers' Society in as flourishing a condition as this year, and more.

SOCIETY OF ENGINEERS

IN THE

UNIVERSITY OF MINNESOTA.

LIST OF MEMBERS,

MAY, 1899.

HONORARY MEMBERS OF ENGINEERS' SOCIETY.

A. B. Choate.
F. W. Springer, E. E.
Geo. L. Wilson, C. E.
Chas. L. Pillsbury.
C. E. Loweth, C. E.
Morgan Brooks.
E. E. Woodman, C. E.
G. Rosenbusch, B. E. E.
C. W. Hall, M. A.
Wm. R. Hoag, C. E.
Geo. D. Shepardson, M. E.
Wm. R. Appleby, B. A.
Frank H. Constant, C. E.
H. Wade Hibbard, M. E.
A. E. Haynes, Dr. S. C.
H. E. Smith, M. E.
W. H. Kirchner, B. S.
J. H. Gill, M. E.
H. T. Eddy, Ph. D.
F. W. Denton, E. M.

LIST OF ACTIVE MEMBERS OF ENGINEERS' SOCIETY.

Allee, D. A.
Anderson, J. G.
Bailey, C. L.
Bayless, H. C.
Bille, C.
Blake, H. B.
Buehler, W.
Christensen, H. J.
Chut, C. E.
Donovan, P. W.
Dow, J. C.
Downing, F. E.
Dugan, E. J.
Everington, J. W.
Gholz, A. L.
Graling, V.
Grime, E. M.
Gundstad.
Higgens, C. C.
Hildebrant, H. A. G.
Huntoon, M. B.
Johnson, F. E.
Kinsell, W. L.
Kreger, A. Z.
Libby, L. D.
McKittrick, J.
MacKusick, E. M.
Midthur, O. J.
Morris, C. R.
Newhall, W. B.
Nilson, W.
Ober, W. M.
Parkhurst, H.
Prendergast, P. S.
Rogers, A. A.
Rosok, J. A.
Schmetz, D.
*Scofield, F. M.
Shepley, C. R.
Sperry, T. A.
Strate, T. H.
Thaler, J. A.
Thompson, J. E.
Tracy, F. G.
Tuller, C. E.
Verharen, A. W.
Warded, E. S.
Warren, J. H.
Whitman, E. A.
Wilson, E.

*Died April 3, 1899.

CORRESPONDING MEMBERS.

1875.

NAME OF RESIDENCE.	DEGREE.	OCCUPATION
Leonard, Henry C. (B. S. '78.) Minneapolis, Minn.	B. C. E.	Physician.
Rank, Samuel A..... Central City, Col.	"	Civil and Mining Engineer.
Stewart, J. Clark..... Minneapolis, Minn.	"	Physician; Prof. of Pathology at University of Minnesota.

1876.

Gillette, Lewis S..... Minneapolis, Minn.	B. C. E.	President of the Gillette-Herzog Manufacturing Co.
Hendrikson, Eugene A..... St. Paul, Minn.	"	Lawyer.
Thayer, Chas. E..... Minneapolis, Minn.	"	Grain Dealer.

1877.

Pardee, Walter S.....B. Arch. Architect.
Minneapolis, Minn.

1878.

Bushnell, Charles S.....B. M. E. Bicycle Manufacturer.
Minneapolis, Minn.

1879.

Dawley, William S.....B. C. E. Chief Engineer C. & E. I. R. R.
Chicago, Ill.
*Furber, Pierce P..... " Died April 6, 1893.

1883.

Barr, John H.....B. M. E. Professor of Machine Design, Cornell University.
Ithaca, N. Y.
Peters, William G.....B. C. E. Vice-President Columbia National Bank.
Tacoma, Wash.
Smith, Louis O..... " Civil Engineer.
Le Sueur, Minn.

1884.

Loy, George J.....B. C. E. Bridge Contractor.
Spokane, Wash.
Matthews, Irving W..... " Real Estate and Abstract of Titles.
Waterville, Wash.

1885.

Bushnell, Elbert E.....B. M. E. Dealer in Typewriters.
New York City.
*Fitzgerald, Patrick T.....B. C. E. Died April 2, 1887.
Reid, Albert I..... " U. S. Inspector of Harbor Improvements.
Racine, Wis.

1886.

Woodmansee, Charles C.....B. Arch. Bookkeeper.
Midway Park, St. Paul.

1887.

Andrews, George C.....B. M. E Heating Manufacturer and Contractor.
Minneapolis, Minn.
Crane, Fremont.....B. C. E. Civil Engineer.
Sand Coulee, Mont.

1888.

Anderson, Christian.....B. C. E. Civil Engineer.
Portland, Ore.
Loe, Eric H.....B. M. E. Mechanical Engineer with Nordyke & Marman.
Minneapolis, Minn.
Morris, John..... " Mechanical Engineer and Assistant Superintend. of the Plano Mfg. Co.
West Pullman, Chicago, Ill.
Hoag, Wm. R. (B. C. E. '84).. C. E. Prof. Civil Engineering U. of M.
Minneapolis, Minn.

1889.

Coe, Clarence S.....B. C E. City Salesman, Wyman, Partridge & Co.
Minneapolis, Minn.

1890.

Burt, John L.....B. C. E. Irrigation Engineer.
Hermosillo, Mex.

Dann, Wilbur W. Minneapolis, Minn.	B. C. E.	Assist. Engineer Lake Superior Power Co.
Gilman, Fred H. Minneapolis, Minn.	"	Editor Mississippi Valley Lumberman.
Greenwood, W. W. Minneapolis, Minn.	"	Editor and publisher of The Christian News.
Hayden, John F. Minneapolis, Minn.	"	Editorial Department Mississippi Valley Lumberman.
Higgins, John T. St. Paul, Minn.	"	Physician.
Hoyt, Wm. H. Duluth, Minn.	"	Assistant U. S. Engineer.
Nilson, Thorwald E. Minneapolis, Minn.	B. M. E.	Reporter.
Smith, William C. St. Paul, Minn.	B. C. E.	Assistant Engineer N. P. R. R.
Woodward, Herbert M. Boston, Mass.	B. M. E.	Teacher in Mechanic Arts High School.

1891.

Aslakson, Baxter M. Dayton, Ohio.	B. M. E.	With the Stillwell-Bierce and Smith-Vaile Co.
Carroll, James E. Minneapolis, Minn.	B. C. E.	Draughtsman City Engineer's Office.
Chowen, Walter A. Buffalo, N. Y.	"	Engineer in charge of G. N. elevator.
Douglas, Fred L. New York City.	"	Exam. Eng. Dept. of Buildings.
Gerry, Martin H., Jr., (B. M. E. '90) Chicago, Ill.	B. E. E.	Supt. motive power of the Metropolitan West Side Elevated R. R. Co.
Huhn, George P. Minneapolis, Minn.	"	Flour City Nat'l Bank.

1892.

Burch, Edward P. Minneapolis, Minn.	B. E. E.	Electrical Engineer Twin City Rapid Transit Co.
Burtis, William H. Decorah, Ia.	"	Electrical engineer and contractor.
Felton, Ralph P. Minneapolis, Minn.	B. M. E.	Ass't State Y. M. C. A. Secretary.
Goodkind, Leo. St. Paul, Minn.	B. Arch.	City Supt. of schoolhouse construction.
Gray, William I. Minneapolis, Minn.	B. E. E.	Electrical contractor.
Hankenson, John J. Minneapolis, Minn.	B. C. E.	Asst. Engr. C. M. & St. P. Ry.
Higgins, Elvin L. Hutchinson, Minn.	B. C. E.	County surveyor of McLeod Co.
Howard, Monroe S. Waukan, Wis.	B. E. E.	Electrical engineer and contractor.
Mann, Frederick Maynard. Philadelphia, Pa.	B. C. E.	Instructor in architectural Design, Univ. of Penn.
Plowman, George T. New York City.	B. Arch.	Sec'y. Goodwin Car Co.

1893.

Anderson, Ole J. St. Peter, Minn.	B. C. E.	Civil Engineer.
Avery, Henry B. Minneapolis, Minn.	B. M. E.	With the Gillette-Herzog Mfg. Co. (Engineering dept.)
Bachelor, Frank L. St. Paul, Minn.	B. C. E.	Head draughtsman St. Paul Foundry Co.
Chase, Arthur W. Hastings, Minn.	B. E. E.	Shoe merchant.
Couper, Geo. B. Northfield, Minn.	B. M. E.	Manager Northfield Electric Light Co.
Dewey, William H. New York City.	B. E. E.	Heating Eng. Dewey Eng. Co.
Erf, John W. Middleton, Conn.	B. C. E.	Draughtsman Berlin Iron Bridge Co.
Guthrie, J. DeMott. Elgin, Minn.	B. E. E.	Physician and Surgeon.
Hoyt, Hiram P. Chicago, Ill.	B. C. E.	Draughtsman with American Bridge Works.
Morse, George H. Minneapolis, Minn.	B. E. E.	Instructor in National School of Electricity.

Reidhead, Frank E..... Minneapolis, Minn.	"	Supt. East Side Station of Minneapolis General Electric Co.
Springer, Frank W..... Minneapolis, Minn.	"	Instructor in University of Minn.
Washburn, D. Cuyler..... Minneapolis, Minn.	B. Arch.	Draughtsman for J. T. Fanning, C. E. Specialists on Water Powers.

1894.

Bray, Geo. E..... Mountain Iron, Minn.	B. M. E.	Electrician for Mountain Iron Mining Co.
Chalmers, Chas. H..... Minneapolis, Minn.	B. E. E.	Manufacturer of Electric Machinery.
Cunningham, Andrew O..... New Orleans, La.	"	With Gillette-Herzog Mfg. Co.
Gill, Jas. H. (B. M. E., '92)	M. E.	Instructor in Metal Work, U. of Minn.
Gilman, Jas. B..... Minneapolis, Minn.	B. C. E.	Draughtsman, Gillette-Herzog Mfg. Company.
Johnson, Noah ..... St. Paul, Minn.	B. C. E.	C. G. W. Ry. Engineering Dept.
Trask, Birney E. (B. C. E., '90).. Highland Park, Ill.	C. E.	Professor of Mathematics, Northwestern Military Academy.
Weeks, William Charles..... Minneapolis, Minn.	B. C. E.	U. S. Assistant Engineer.

1895.

Adams, Geo. F..... Newark, N. J.	B. E. E.	Electrical Engineer.
Bishman, A. E..... Willmar, Minn.	"	Chief Engineer of Lighting Plant.
Bohland, John A..... St. Paul, Minn.	B. C. E.	Draughtsman, Bridge Dept., Gt. Nor. R. R.
Casseday, Geo. A..... St. Paul, Minn.	"	Draughtsman, Bridge Dept., Gt. Nor. R. R.
Chapman, Leslie H..... St. Paul, Minn.	"	Bridge Dept., Gt. Nor. R. R.
Cutler, Harry C..... Gibensville, Idaho.	(B. E. M. '94) E. M.	Chemist and Assayer, with American Developing and Mining Co.
Christianson, Peter Minneapolis, Minn.	(B. E. M. '94) E. M.	Instructor, Univ. of Minn.
Eddy, Horace T..... Schenectady, N. Y.	B. E. E.	With General Electric Co.
Rounds, Fred M..... Dallas, Texas.	"	Engineering Dept., Southwestern Tel. and Tel. Co.
Shepherd, B. P..... Minneapolis, Minn.	B. M. E.	Draughtsman.
Tanner, H. L..... Decorah, Iowa.	B. E. E.	Sect. Decorah Electric Light Co.
Tilderquist, William..... Spokane, Wash.	B. M. E.	With Edison Electric Co.
Von Schlegell, F..... Minneapolis, Minn.	B. E. E.	Bridge Dept., Gt. Nor. R. R.
Weaver, A. C..... Minneapolis, Minn.	B. M. E.	Track Recorder, Chi. Gt. West. Ry.
Wilkinson, Chas. Dean..... Whitehall, Mont.	B. E. M.	Manager Gold Hill Mining Co.

1896.

Beyer, Adam C..... Elmira, N. Y.	B. C. E.	Ass't Inspector for The Osborne Company, Cleveland, Ohio.
Burch, Albert M..... St. Paul, Minn.	"	Draughtsman, Bridge Dept., Gt. Nor. P. R. R.
Erikson, Henry A..... Rochester, Minn.	B. E. E.	Teacher.
Hastings, Clive..... Brainerd, Minn.	B. M. E.	Special Machinists' Apprentice, Nor. R. R.
Hilferty, Chas. D..... Allegheny, Penn.	"	Draughtsman, Pitt's Locomotive and Car Works.
Hughes, Thos. M..... Congress, Arizona.	B. E. M.	Mining Engineer.
Hugo, Victor ..... Duluth, Minn.	B. M. E.	Mechanical Engineer.
Jones, C. P..... Minneapolis, Minn.	B. C. E.	Civil Engineer.
Lang, James S..... Boston, Mass.	M. E.	With West End Electric R. R. Co.

Long ..... Hayland, Georgia.	B. C. E.	Ass't Engineer, Georgia & Florida R. R.
Magnusen, C. Edw..... St. Peter, Minn.	B. E. E.	Instructor in Sciences, High School.
May, Albert E..... Bourne, Baker Co., Ore.	B. E. M.	Ass't Manager North Pole Mine.
Tanner, Wallace N..... Great Falls, Mont.	"	Smelting Dept., Boston & Montana C. C. & S. M. & S. Co.
Wheeler, Herbert M..... Ft. Wayne, Indiana.	B. E. E.	Fort Wayne Electric Corporation.

1897.

Abbot, L. A..... Minneapolis, Minn.	E. E.	Electrical Engineer, D. & D. Elec. Co.
Becker, Geo. A..... Kaslo, B. C.	E. M.	Assayer and Chemist.
Blake, R. P..... Brainerd, Minn.	M. E.	Special Apprentice, N. P. R. R.
Chapin, Lewis P..... Boston, Mass.		Instructor in Chemistry, Mass. Inst. of Technology.
Chesnut, G. L..... Minneapolis, Minn.	E. E.	Electrical Engineer, Gen. Elec. Co.
Craig, Robert..... Minneapolis, Minn.	M. E.	Salesman, Hilbrook Mfg. Co.
Cross, Chas. H..... Brainerd, Minn.	"	Special apprentice, N. P. R. R.
Hamilton, H. C..... Sharon, Penn.	Chem. E.	Chemist, Sharon Steel Works.
Hewitt, F. M..... Minneapolis, Minn.	C. E.	Civil Engineer.
Hibbard, Truman..... Hudson, Wis.	E. E.	Mang. Willow River Elec. Light & Power Co.
Lee, E. A..... Minneapolis, Minn.	C. E.	Draughtsman, Gillette-Herzog Manufacturing Company.
Linton, James H..... St. Paul, Minn.	Chem. E.	Chemist.
Lonie, J. H..... St. Paul, Minn.	M. E.	Draughtsman, Chicago-Great Western Railroad.
Markhus, O. G. F..... Willmar, Minn.	E. E.	City Electrician .
Miller, W. L..... Winona, Minn.	"	City Engineer.
Mills, E. C..... Minneapolis, Minn.	E. M.	Instructor in Mining, University of Minnesota.
Myers, M. A..... Minneapolis, Minn.	E. E.	Electrical Engineer, General Electric Company.
Savage, E. S..... Minneapolis, Minn.	M. E.	Mechanical Engineer, Twin City Iron Works.
Silliman, H. D..... Mount Iron, Minn.	"	With Oliver Iron Mining Company.
Webber, W. W..... St. Paul, Minn.	Chem. E.	Chemist.

1898.

Brackenbury, C..... Sparta, Minn.	E. M.	With Minn. Loon Co.
Dahl, H. F. M..... Minneapolis, Minn.	E. E.	Electrical Engineer, Twin City Rapid Transit Co.
Gilchrest, C. C..... Chicago, Ill.	E. E.	Telephone department, Western Electric Co.
Glass, C. A..... West Superior, Wis.	C. E.	Engineer at Steel Barge Works.
McIntosh, J. B..... Houghton, Mich.	E. M.	With the Winona Copper Co.
McKellip, F. W..... Minneapolis, Minn.	E. E.	Electrical Engineer, Minneapolis General Elec. Co.
Pratt, G. E..... Cotain, Peru.	E. M.	Mining expert.
Smith, H. A..... Minneapolis, Minn.	E. M.	With Gellette-Herzog Co.
Taylor, E..... Portland, Ore.	C. E.	Civil Engineer.
Wagner, H..... Minneapolis, Minn.	E. E.	Meter department, Mp'l's General Elec. Co.
Walker, C. L..... Minneapolis, Minn.	E. M.	Mining Engineer.

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1900.

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Table of Contents.

The Plant of the Faribault Consolidated Gas and Electric Company, - - - - - - - - - - - - - - - - - - Oliver Field Allen..... 1

Survey and Construction of the Cascade Tunnel by the Great Northern Rail way through the Cascade Range, State of Washington, - - - - - - - - - - - - - - - M. E. Reed, Assistant Engineer G. N. Ry.... 11

Wind Power for Electrical Purposes, - - - - - Roy E. Thompson.....18

The Resident Engineer, - - - - - - - Frank H. Constant, C. E 22

Secondary Stresses in Framed Structures, - - Thomas A. Clark, C. E. 32

Photography, - - - - - - - - - - - - - - W. R. Hoag.....39

The New Mechanical Engineering Shops of the University of Minnesota, - J. J. Flather.....42

Train Resistances, - - - - - - - - - - - - Lester Daniel.....45

Pressure and Power to Roll Sheet Metal, - - - - - - - - - - - - - - - - - W. P. Richardson and E. K. Wennerlund.....50

PROF. JOHN J. FLATHER, Ph. B., M. M. E.
Professor of Mechanical Engineering,
University of Minnesota.

THE

YEAR BOOK

OF THE

SOCIETY OF ENGINEERS

UNIVERSITY OF MINNESOTA

MAY, 1900

THE PLANT OF THE FARIBAULT CONSOLIDATED GAS AND ELECTRIC COMPANY.

OLIVER FIELD ALLEN.

Faribault, Minnesota, is a town of about nine thousand inhabitants, located in a distinctly agricultural district and practically devoid of manufacturing interests. It is a place filled with well built, attractive homes, and has the necessary stores and small shops to supply them and the surrounding farms with food, clothing and other usual merchandise. There are several state and public institutions which add to the attractiveness of the town in many ways.

The lighting and power business in Faribault was in a peculiar condition when the writer first visited the town a little over a year ago. Two companies were engaged in the lighting business. The Polar Star Electric Company—organized some three years before with local capital and operated by local business men—had the contract for street lighting and a considerable part of the commercial electric lighting. This company was operating in an old flouring mill with Corliss

engines, assisted by a small water power. The Consolidated Gas & Electric Company, controlled by eastern capital, the outcome of the Faribault Gas Company of twenty years ago, and a competing Electric Company of more recent date, was operating an electric station equipped throughout with Thomson-Houston electric apparatus, slide valve engines and horizontal return tube boilers. Its station had been of the best in its day, but was obviously not very economical when judged by present standards. Its gas department had a new and highly efficient gas making apparatus, but was hampered by small storage capacity and small trunk mains.

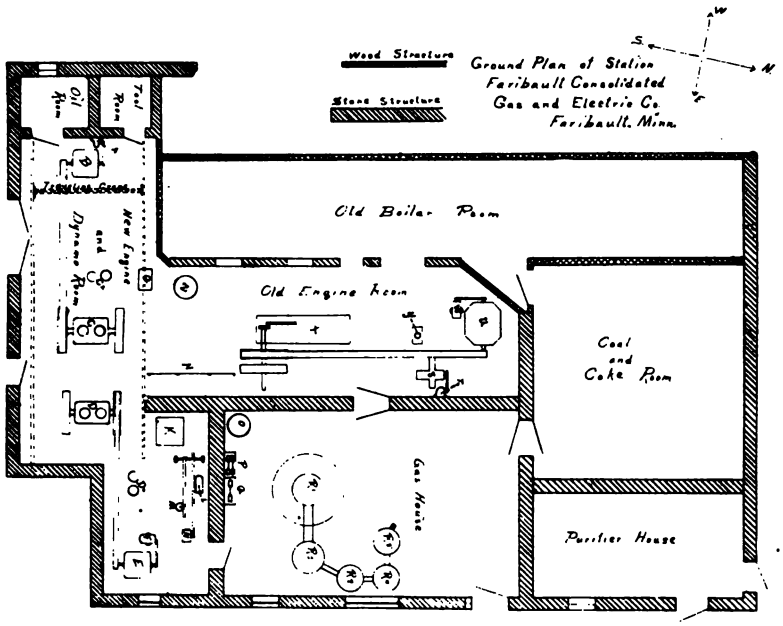
The problem to be solved was to reconstruct the Consolidated Company's plant so as to at once give satisfactory service at lowest fuel cost, and decrease as far as possible the fixed charges, which form of necessity a large percentage of the total cost of out-put of a small station.

Faribault is so far from the coal mines that freights constitute about 50% of the cost of all fuel. It was decided, therefore, to use as far as possible that fuel having the highest actual available efficiency per pound, and consequently reduce the percentage of operating expenses going to transportation.

The labor item is another factor of great importance and it was decided to arrange the plant so that a minimum of attendance should be required in operating. The final chief considerations were for a plant having the lowest possible depreciation, maintenance, and fire hazard expense. With these ends in view the reconstruction was undertaken and the resulting plant will now be described.

The plant is located six blocks north and one block east of the business and population center of the town. It is on the west bank of Straight river and has been provided with a spur track from the Chicago Great Western railroad. This spur comes up a long incline which permits of all coal being shoveled down from car to furnace. The general arrangement is shown by the plan. The Purifying House is of stone with all iron roof and contains the gas purifiers. The gas house is also of stone and iron and contains the gas making apparatus and steam pumps. It is shut off from the engine room and fuel sheds by fire doors of approved construction. The New Engine and Dynamo

Room is of stone on the east and south sides but is a temporary wood structure where it joins with the older boiler house and engine room, both being wooden buildings. When the larger power unit referred to later is installed it is expected that this main building will be completed and the entire plant made fire-proof. There is a fire-proof oil room for the storage of all oils, paints, waste, etc., and next to it a tool room for all sorts of tools and such supplies as packing, extra machine parts, etc.



We will disregard the steam plant as not being at all unusual and consider only the new or reconstructed part of the plant. The arrangement of the different elements of machinery should be noted. The switchboard (H) is in the center of the group. It has on it both electrical and gas indicating instruments and shows the engineer in charge the condition of every part of the plant. When facing it a step to the left takes him to the steam engine (X) and gas pressure regulator (Y); a step to the right and he is at both gas engines (C and D); a half dozen steps around the corner and he is in the gas house. He can thus put his hands on any machine in the plant five seconds

after leaving the switchboard. It is all under one roof—all accessible and yet divided by fire proof walls and the electrical apparatus protected from the dirt and dust of the gas house.

The Gas producing machinery consists of a standard 4-foot Junior Lowe Water Gas setting installed in 1897. The setting comprehends a Generator (R_1), Superheater (R_2), Seal (R_3), Scrubber (R_4) and condenser (R_5). There is a No. 4 Sturdevant fan blower (L) driven by a 5 H. P. single phase induction motor (N) for furnishing air blast to the gas machinery. A small steam boiler (O) in the Gas house furnishes the steam for the generator and for pumping oil into the apparatus and water into the elevated storage tank from which it runs through the seal and scrubber.

The process of manufacture is as follows: The generator (R_1) after being filled nearly full of coke (almost pure carbon) is fired and blasted by the fan blower. The products of this combustion are carried through the super heater (R_2) which is filled with checker brick and exhausted to atmosphere at its top. After these brick are heated to a very high temperature the blast is discontinued and steam (H_2O) is admitted at the base of the fire. The incandescent carbon in the generator has a greater affinity for the oxygen of the steam than the hydrogen has; the carbon and oxygen combine to form carbonic oxide (CO) and the hydrogen (H) is liberated. The carbonic oxide is non-luminous or blue water gas. It has no illuminating property and burns with a blue flame. Its calorific value is relatively low, about 350 B. T. U. per cubic foot. To fit it for general use it must be enriched or carburretted. This is effected by introducing at the top of the generator gas oil of about 40° Baume gravity, which has been heated to a gaseous state, the hydro carbon vapor of the gas oil and the water gas and hydrogen mingle as they pass from the generator to the superheater and when subjected to the excessive heat of the checker bricks they form chemical combinations, the hydro carbon compounds which make up ordinary illuminating gas. Its average composition is as follows (the ingredients are given in the order of their volumetric value): Saturated hydro carbons, methane, ethylene, etc., carbon monoxide, hydrogen and traces of oxygen, nitrogen and carbonic acid.

The fixed gas passes from the top of the superheater to the seal (R_3) where it bubbles through water, then up through the scrubber (R_4) where it is washed with water trickling over a lattice work of wood slats and down through the condenser (R_5) also having water pipes in it. From this last vessel it goes to the relief holder—a gasometer, formerly used as a storage holder, having a capacity of about eight thousand cubic feet. From the relief holder the gas is pumped by a double revolver Root's exhauster (S) driven by a 1 H. P. induction motor (T) through the purifying boxes into the main storage gasometer. The two purifying boxes are of the ordinary type with trays and the purifying material is made on the premises of shavings, iron borings, lime and copperas and when exhausted is revivified on a cement floor above the coal and coke sheds to which it is easily shoveled from the boxes.

The capacity of the gas making apparatus is five thousand cubic feet per hour, twenty-four hours a day, and the new gasometer holds 62000 cubic feet. This holder was built last summer of very heavy steel plates and has a natural pressure of 4″ of water. The sides of the tank are of stone masonry lined with a nine inch brick wall and between brick and stone is a layer of Portland cement grouting 2″ thick. The bottom of the tank is made of three layers of concrete covered by one inch of solid Portland cement.

After leaving the gasometer the gas comes back to the station and passes through a Connelly Automatic Governor (Y) which reduces the pressure to that desired on the consumer's meters. This governor consists of a balanced valve having two seats and two discs. The gas enters between these two seats and passes up through one and down through the other, the two streams uniting in the case. The valve discs are supported by a small inverted basin about two feet in diameter floating in water and counter balanced over knife edged bearings for a fixed pressure which is determined by the number of counter weights used. The outgoing gas connects with the inside of this inverted basin or miniature gasometer and any change in pressure immediately moves the valve by lifting the basin and closing the valve if increasing pressure or dropping and opening the valve if decreasing pressure. So nicely is this

valve and its center balance arranged that less than 1-10" change in pressure is sufficient to operate it from almost no gas passing to full capacity.

From the regulator the gas passes to the mains and thence to consumer's meters. These are of the usual type of dry meter. Most of those in use are the ordinary cubic foot registering meters, but recently several prepayment or quarter-in-the-slot meters have been installed and give excellent satisfaction.

On the switchboard is a jet photometer showing at all times the candle power of gas going into the city mains, and pressure gauges showing the gas pressure at the following points: Outlet of gas making apparatus, outlet of relief holder, outlet of exhauster, outlet of purifiers, outlet of large gas holder, outlet of regulator. The engineer in charge can tell by these six gauges the condition of every part of the gas plant; and he can attend to all parts which are likely to need attention, without going out of hearing of the electric machinery.

Perhaps the most novel part of the plant is the gas engine equipment. Preliminary to installing a large gas engine generating set two small ones have been put in, one 11x12 two cylinder vertical Westinghouse gas engine (C) belted direct to a new 30 K. W. single phase General Electric Co. alternator (B) and one 9x11 two cylinder engine (D) of the same type belted direct to an 18 K. W., T. H alternator (E). These engines are of the four stroke cycle type with cam actuated valves and electric ignitors. Both pistons are set on the same side of shaft and one is two strokes ahead of the other so that the engine has one positive stroke each revolution. The mixture is controlled by a compound cylinder valve, which is at the same time the throttle of the engine. The governor balls act directly on this valve and open and close the gas and air ports, always maintaining the proportion to which the ports are adjusted. The gas supply is through a regulator which delivers gas at atmospheric pressure and consequently the proportion of gas and air is constant, no matter how nearly open or shut the intake ports may be.

The regulation, as has been indicated, is accomplished by throttling the supply of explosive mixture, and each cylinder has a positive power stroke every cycle. The intensity of the

stroke varies with the work being done. The cranks are enclosed and cranks, bearings and cylinders are lubricated from the oil in the crank case. The lubrication of cylinders has proved highly satisfactory.

One cylinder in each engine is equipped with valves on the principle of a steam engine and the engines are started by compressed air kept stored in tanks and replenished by a small pump (M) driven by the motor which drives the fan blower. As soon as the engine attains a speed from air in one cylinder, the gas is exploded in the other and the air shut off. The excessive heat of the cylinder is removed by circulating the water in the large Gas Holder Tank through water jackets. The water is circulated by means of a small electrically driven pump and the 400,000 gallons available form the most perfect kind of supply, while the heat from the engines keeps the Holder Tank from freezing in the coldest weather. The jackets are also connected to the city water service so that a break down of the circulating system would not interfere with the operation of the engines.

The ignitors have two sources of electrical supply. A twelve cell battery of Edison Lalande cells, and a 12 Volt, 15 Ampere continuous current generator (G) direct connected to a ½ H. P. induction motor. On the switchboard are volt and ampere meters showing at all times the current used by the ignitors and switches for changing one or both engines from battery to generator or vice versa, and for changing polarity of current supplied to ignitors.

The exhaust gases pass from the engines under the floor to tanks (C_2 and D_2) about 18″ in diameter and five feet long. These are connected in series and from them the exhaust passes to a common pipe going under the floor and out to a waste below the building and also up above the roof. The combination of pipes and tanks not only *absolutely* removes all noise of exhaust, but the tanks radiate enough heat to keep the engine room properly heated in winter.

A traveling crane makes it easy for the engineer to remove or replace any heavy parts. The speed of the 11x12 engine is 290 r. p. m., and the 9x11, 300 r. p. m. The regulation of the gas engines is exceedingly good. The larger engine is used to

carry the main city circuit from starting up time in the afternoon till the load gets too big for it, when the steam plant is started. About eleven all the electric load is transferred to the smaller gas engine and it carries it through the night and also picks up the morning load. There is a Bristol Recording Volt Meter at the office connected to the secondary of a 30 K. W. transformer, which is a block and a half from the office and lights the principal business section. This meter records voltage as it really is at the lamps of the chief customers. The card reproduced, Feb. 4-5, 1900, is a fair sample. It shows the plant started up at 4:45 p. m., when the load was taken by the 11x12 gas engine and carried until 7 o'clock when the steam plant was started. The steam plant ran until 10:40 when the 9x11 gas engine was turned on and it ran through until 8:05 a. m., when the plant shut down. At midnight, 1:30 and 5:18 a. m., the engineer changed the voltage by hand for some reason.

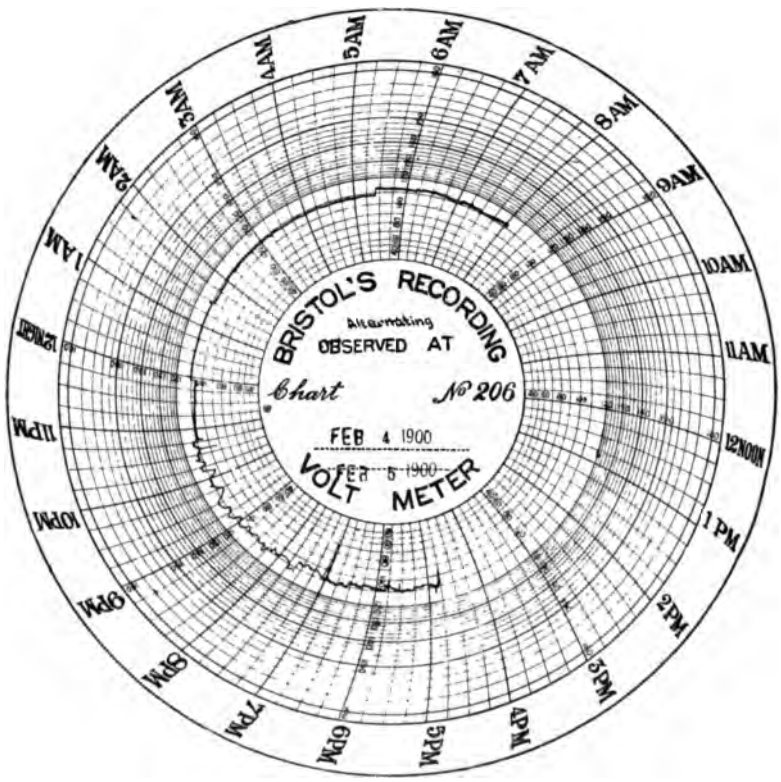
The 11 x 12 engine is rated at 50 B. H. P. and has successfully developed 59. The 9 x 11 is rated at 30 B. H. P. and has developed 40 B. H. P.

All gas going to the engines is metered by a three foot "station" meter (K) and its temperature is shown at the meter. The consumption of gas has been as low as at other places and the economy of operation is all that was expected when the engines were bought.

The three dynamos (B, E and U) are all single phase 125 cycle 1100 Volt alternators, separately excited (exciters A, F and W) and compound wound. The connections to switchboard are under ground with lead covered cables drawn through vitrified clay conduit. The switchboard is of marble two inches thick, supported on steel frames and equipped with new General Electric Co. instruments. Each lighting circuit is on a throw-over switch and can be run from either of two sets of bus bars. All output is measured by primary recording watt meters. There are secondary recording watt meters on all motors and lights in station. So not only is all the output measured but all power used in each branch of the plant is also measured. There is a volt meter on main city circuit in the gas

house so the engineer can know just how the electric plant is going when he makes the gas.

The arc lamps are supplied by an alternating current transformer (Z) having an 1100 Volt primary coil at constant potential and a 6.6 Ampere secondary coil at constant current and variable potential according to the number of lamps connected. The two coils are in a closed magnetic field and the regulation is effected by one coil moving from and towards the other.



The primary is stationary and the secondary suspended by counter weights over knife edge bearings. The automatic movement of the coil controls the secondary current and maintains it at the fixed quantity to which the transformer is set. The regulation of this instrument is unusually good. The lamps are series enclosed long burning arc lamps and a few series in-

candescent lamps are used in the same circuit. The arc lamps consume about 450 watts each.

The four auxiliary motors are all supplied from one Type H. General Electric Co. Transformer with 104 volt secondary. These motors are of the induction type, single phase, self starting and built by the General Electric Co.

The transformer equipment on the streets is chiefly Type H. General Electric Co. transformers with secondaries set at 104 and practically all services are metered with Thomson Recording Watt meters.

The reconstructed plant is proving highly efficient as to labor and fuel expense, and it is believed that the repairs and depreciation will be much below the average for plants with the same capacity of output.

SURVEY AND CONSTRUCTION OF THE CASCADE TUNNEL BY THE GREAT NORTHERN RAILWAY THROUGH THE CASCADE RANGE, STATE OF WASHINGTON.

M. E. REED, Assistant Engineer, Great Northern Railway.

Modern methods have to a great extent revolutionized tunnel driving. The successful tunnel man of to-day must have many qualifications which were not deemed necessary a decade ago. First and foremost he must be a good organizer, a man who knows how to handle a rough class of men and a man who is what is known as a "pusher." Then he must be a good rock man to whom "bad ground" has no terrors and who thoroughly understands the use of explosives. But besides these qualifications he must be versed in both electricity and compressed air; in steam engines and boilers; in ventilating fans and pumps; in rock crushers and concrete mixers; in specifications for good cement and the proper placing of concrete. In fact, in the innumerable details which go to make up an up-to-date tunnel plant. No man can be an expert in all these different lines, yet a good tunnel man should have a general knowledge of each of these subjects so that he may know if the men in charge of these departments are well informed in their own particular branches.

The Great Northern Railway Company is hastening the completion of a tunnel through the summit of the Cascade Mountains, in the construction of which the most improved methods are being employed.

Since the completion of the main line to the coast in 1893, the road over the divide has been operated by means of a "switch-back" through Stevens' Pass. This pass was discovered by Jno. F. Stevens while making reconnoisance for a line to tide water. The writer has not the data which led to the selection of this route but understands that there were so many points in its favor that no other line was seriously considered. The general route once decided upon, every effort was

made to hasten the location and construction of a line in which the first cost should be a minimum and yet the location should readily admit of revisions when increase of business and capital should warrant a more expensive and economical construction. The building of a trans-continental line without governmental aid was a daring undertaking in 1890—1893. The probable income of the road was at best a rough estimate and strict rules of location had to be modified to suit the conditions. A switch-back through Stevens' Pass fulfilled the requirements of minimum first cost, being constructed in a temporary manner with steep grades and excessive curvature. From the first, considered only as a make shift, it has proved to be a most expensive line to operate, due not alone to the excessive grades but to the heavy fall of snow, some winters reaching from 16 to 18 feet on the level.

In 1896 President Hill negotiated a loan for the construction of the tunnel which should supplant the switch-back. Construction of the approaches was commenced in January, 1897, and of the tunnel proper in Aug. 20 of the same year. Length of tunnel, 13,383. Summit elevation of tunnel at East Portal, 3,375 feet above sea level. Summit elevation of switch-back, 4,052 feet above sea level. Rise and fall saved by tunnel, 677 feet. Distance saved by tunnel, 10.1 miles. Curvature saved by tunnel, 2,332°. Grade on switch-back, east side, .035%. Grade on switch-back west side, .040%. Grade in tunnel, .017%. Grade of mountain divisions each side of tunnel, .022%. Schedule time of passenger trains over switch-back 1h, 20m. Schedule time of freight trains over switch-back, 2h, 40m.

SURVEY OF TUNNEL LINE.

The tunnel is on a tangent, which simplifies the careful location of the line. As will be seen by referring to the profile, plate A, the mountain over the tunnel has two summits with a considerable sag between them. On each of these summits transit stations were located, from which could be seen stations at each portal. Towers were erected at each of these summits. In the center of these towers gas pipe targets were secured and carefully plumbed on the center line. These targets were twenty feet high, so as to reach above the snow in the

THE SWITCHBACK THROUGH STEVENS PASS

winter time. Intermediate foresights were located along the mountain side to be used when the summit targets were obscured by clouds. All transit points were checked by repeated observations by different observers. Check levels were run over the pass, bench marks being established each 100 feet in elevation. These levels have been checked by four different observers with satisfactory results.

The length of the tunnel was obtained by direct measurments, as it did not seem advisable to employ any system of triangulation. The first measurements were made with steel tape and plumb bob. In checking the distance the system of slope measurements was resorted to, using a 400 foot tape. Permanent measurement points were established with the transit on true center line and as nearly 400 feet apart as the nature of the ground would permit. These points were placed either on high stumps, which were plentiful, on braces nailed to trees, or on plugs driven in holes drilled in rock cliffs. The elevations of these points were taken carefully with the level, and the distance along the slope measured with the 400 foot tape, the tension on the tape being regulated by a spring balance and the temperature noted at each end of the tape. Most of the measurements were taken while the sun was obscured by clouds. From these slope measurements, corrected for temperature, and the vertical distances between stations, the horizontal distances were calculated—all measurements, levels, lines, etc., were checked by two or more observers working independently. A base line was established at the West Portal for testing tape, and for arriving at the proper tension to be applied to the 400 ft. tape and for fractions thereof.

In carrying center line in the tunnel, platforms were erected for the transitman, about 800 ft. apart, at the height of the wall plate. These platforms had two independent floors a few inches apart, the lower to support the transit and the upper the transit-man, so there should be no vibration when the transit-man walked around the instrument. Trains to and from the heading passed under these platforms, and in no way interfered with the engineer. Electric lights, carefully centered, served as

back sights. Transit points were placed in the crown of the arc. Bench marks were carried along on the plumb-posts.

MATERIAL.

With the exception of the first 500 feet at the west end the material encountered is a medium hard light gray granite which disintegrates somewhat on exposure to the atmosphere and is quite badly seamed. The rock is not uniform in character and in many cases the seams are loose and filled with a soft soapy talc usually carrying water and very treacherous. In a few cases veins of soft black slaty material cut the formation. The dark seams carry much water and may be usually classed as "bad grounds." So far no mineral has been uncovered.

Timbering has been found to be necessary throughout the entire tunnel. In dangerous or doubtful grounds the arch timbers are carried ahead of the bench and in the most dangerous ground the timbering is advanced to within a few feet of the breast. The American system of timbering with plumb post, wall plate, and five segment arch is employed. As seen from Plate B, timbers in solid rock sections are to be removed previous to placing the permanent concrete lining.

ROCK EXCAVATION.

Four columns are used at the breast. The two center columns carry two drills each and the two side columns one drill each. From 24 to 28 holes are drilled in the breast and are fired in three rounds. These holes are from 9 to 11 feet deep. The bench is taken out in two lifts using from four to eight drills mounted on tripods. All blasts are fired by electricity from the trolley line. Rock from the heading is wheeled in barrows onto a large carriage called the "Jumbo" where it is dumped through chutes into muck cars. The rock from the bench is thrown direct into cars or if too large to be moved by hand is elevated into the cars by an air hoist on the "Jumbo." Whenever any blasting is to be done this "Jumbo" is hauled back two or three hundred feet to avoid falling rocks.

EXCAVATION IN SOFT GROUND.

Perhaps the most interesting part of the work was the excavation of the first five hundred feet of the west end, through a slide composed of gravel and large boulders. This ground

was heavily impregnated with water, and the pressure was at times enormous. The excessive flow of water taxed both the skill and the patience of the miners, and much credit is due those directly in charge that no serious accidents occurred. Space does not permit a detailed account of the method of procedure. Plate "C" will give an idea of the order in which the work was done. The advanced heading or drift "A" was first driven, and the center segment of the timber arch placed in position, proper allowance being made for settlement. Then the two drifts "B" and "B" were driven, of sufficient size to receive the wall plates and the "crowfoot" segments. "C" and "C" being excavated, permitted the placing of the quarter segments and thus completing the timber arch. After "D" was taken out a second set of timbers was placed inside the first to help carry the weight. The bench "E" and "F" was taken out in two lifts when the two sets of plumb posts were inserted completing the timber lining. Polling boards were driven around all drifts and along the side walls. Hay was found to be serviceable in stopping the flow of the wet sand through the spaces between the polling boards. The arch timbers were either spaced, four foot centers, or solid; depending on the weight of the ground to be supported.

Ventilation is accomplished by means of a 24 inch galvanized iron pipe leading to the heading. The foul air is extracted by a Sturtevant fan at 1,350 revolutions. The compressed air liberated from the drills and pumps adds materially to the supply of cool fresh air. It is usually possible to return to work in from fifteen to thirty minutes after a round of holes has been fired.

The grade descending from the East Portal necessitates the pumping of a large volume of water at that end of the tunnel. At date of writing, January, 1900, a million gallons per day are being pumped. Pumps are operated by compressed air.

Electric motors haul all trains in the tunnel whether loaded with workmen going to or from the heading, or timber, rocks, or concrete for the permanent lining. From ten to sixteen one-yard dump cars constitute a train. Both the tunnel and the camps are well lighted with incandescent lights. The voltage

is reduced, with a rotary transformer, from 500 to 100 volts where the wires are liable to be exposed in the heading.

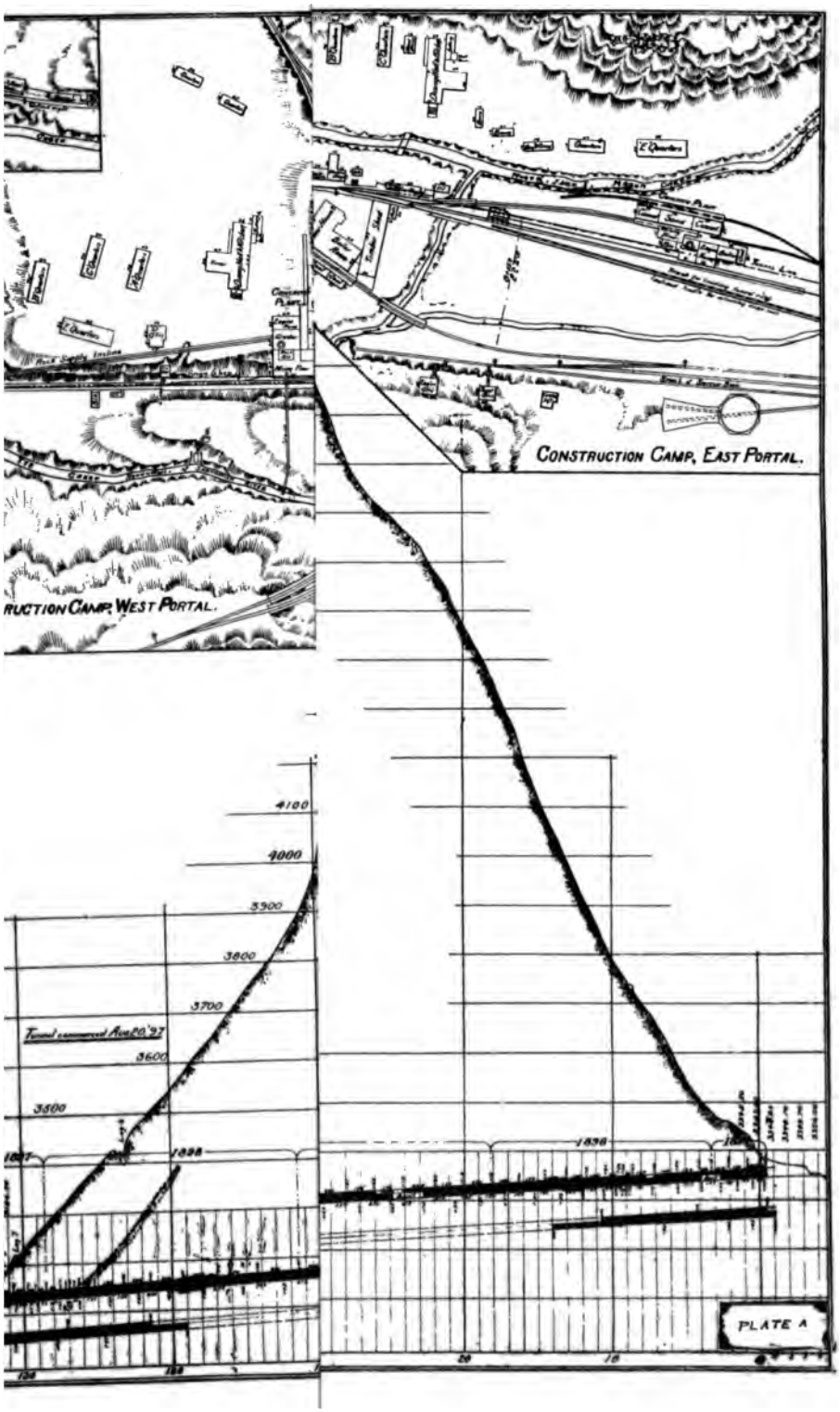
Machine shops at each portal are well equipped for doing all ordinary repair work and for making a portion of the drill extras. Gravity water system supplies both the tunnel plant and the camps with an abundance of pure water. All important buildings are piped and the officers quarters are furnished with bath rooms with hot and cold water.

CONCRETE LINING.

Most complete concreting plants have been installed at each portal. The first concrete was placed in the tunnel in November, 1899. During the first full month, December, over 1,000 feet of tunnel was lined. The method of prosecuting this part of the work is thought to be new in some respects. It was imperative that the placing of the concrete should in no way interfere with the progress of driving the tunnel. To insure this result all work possible connected with the concreting is done from a platform erected at the elevation of the wall plate, allowing muck trains from the heading to pass underneath. This platform is erected in sections five hundred feet long and reached by an incline up which the dump cars loaded with concrete are hauled by a cable and air hoist, which hoist also operates a continuous cable delivering the cars at any desired point along this platform. Electric moters haul the trains loaded with concrete from the mixing plant to the foot of this incline. While each five hundred feet of tunnel is being concreted the next five hundred feet of platform is being erected along with the incline leading to it. Side walls are built in alternate sections of eight feet each so as not to remove all the plumb posts at once. Centers are built in twelve-foot sections, and on being struck are moved ahead on dollies.

The 24-inch ventilating pipe is suspended below this platform out of the way of the tunnel trains and protected from fall of rock from the roof when the timbers are removed. The compressed air and the water pipes are laid in the center of the tunnel on the floor and are depressed whenever a cross-over is required.

The rock is worked away from the face of the concrete walls with a spade, the result being a very smooth surface.


CONSTRUCTION CAMP, EAST PORTAL.
RUCTION CAMP, WEST PORTAL.
4100
4000
3900
3800
3700
Tunnel commenced Aug 20 '27
3600
3500
PLATE A

Tunnel Section
through soft heavy ground

Tunnel Section
through solid rock

Concrete around the arch is mixed dry and well tamped. (See plate "B" for method of concreting.)

PROGRESS OF TUNNEL.

For the first eight months the progress for various reasons was slow. This was especially true at the West Portal while working through the soft ground. During the months of March, April and May, 1898, the weekly progress at the West Portal was less than six feet. For the year ending December 31, 1899, the average daily progress of tunnel, both ends, was 14.6 feet; average monthly progress, both ends, was 443 feet, making the total tunnel for the year 5320 feet; best week, heading, one end, 93 feet; best week, bench, one end, 77 feet; best week, tunnel, one end, 76 feet; best week, tunnel, both ends, 132 feet; best month, tunnel, one end, 303 feet; best month, tunnel, both ends, 527 feet. Total completed, January 1, 1900, 9144 feet. Total to be completed, 4109 feet. Total, length 13253 feet.

About 500 men are employed at each portal, all work being done by the Engineering Department of the railway company, which also runs the boarding camps and the stores. It is expected that the tunnel will be completed and lined with concrete ready to turn over to the Operating Department by January 1, 1901.

WIND POWER FOR ELECTRICAL PURPOSES.

ROY E. THOMPSON.

The two general methods by which wind power may be applied to the generation of electrical energy are: first, by connecting the dynamo directly to the wind-mill shafting by belts and belt wheels, and second by using a wind-mill to pump water into a large tank, the water to be used to drive a water wheel belted to a dynamo. The direct coupled method is much cheaper but is more difficult to manage, by reason of the very great changes in speed.

Up to the last few years the wind-mills used to develop electric power, where the dynamo was directly connected, ranged from 12 to 35 feet in diameter, this range of sizes in a fairly windy country, with a 10 to 25 mile wind, will deliver from 1 to 8 horse power to the dynamo. A 14-foot mill geared from 35 R. P. M. to 3,000 R. P. M. gives one horse power to the dynamo in a 15 to 18 mile breeze, this being the average rate of wind in the west central part of United States.

Wind mills are governed in four different ways; these are centrifugal governing, solid wheel side vane governing, combined side governing vane and brake, and side wheel governors. Of these the centrifugal governing wheel is the best as in this form the sections of fans are so arranged that the whirling action of the wheel tends to change the direction of the sections to a position more nearly parallel to the course of the wind, thus presenting less surface for the wind to act against and consequently reducing the power. This form of governing is made to work by the rotation of the wheel, in which the weight of the fan sections act as the balls of a ball governor, to throw the fan surface out of the wind.

The next form of governing the mill in order of excellence, is the side vane governor with brake. In this form the wheel sections are fastened solidly to the supporting radial arms. Just back of the wheel and projecting a little way beyond it, is a vane which acts, by reason of the force of the wind, in such a manner as to turn the wheel face out of the wind, the guide

vane in the meantime turning so as to be more nearly parallel to the plane of the wheel surface. In addition to this the brake is applied to prevent sudden changes of speed.

The side wheel governor is suitable only for pumping purposes and the brake governor is too hard on the mechanism to be used alone.

Other schemes of governing are those in which automatic belt shifters are used, but these, too, depend on change of speed; so the difficulties experienced by irregular speed are not gotten rid of. Even the best winds vary considerably in speed, due, mainly to eddy currents and changes in the wind caused by surrounding elevations. To remove as much as possible the effect of neighboring elevations, hills, buildings, etc., it is necessary to raise the mill wheel above the interrupted air currents so that the eddies caused by the obstacles shall not influence the working of the wheel. This may be accomplished by elevating the wheel thirty or thirty-five feet above the surrounding obstacles, at which height it is found that the effect of eddy currents is nearly done away with.

In thinking of directly connecting the dynamo to the mill shafting it is necessary to consider the probable number of windy days, the number of days of no wind, and the average rate the wind blows. Assuming as known the amount of electric energy to be supplied, it is then possible to determine the approximate size of the storage battery needed. Having given the speed and horse-power of the dynamo necessary to furnish the energy, one may then select the size of wheel required to generate the needed power.

The next consideration is the means of coupling the mill wheel to the dynamo. This is accomplished by one of two methods; the geared shafting and the reciprocating pump rod. By use of gears and axles, with belt wheels attached, any desired speed may be obtained and by a means which is not easily gotten out of order. When the reciprocating pump rod is to be used, a ratchet movement must be provided, but as the pump rod moves with a harmonic motion it is necessary to provide a heavy balance wheel to insure compaatively steady motion. This scheme is not much used as it is easily gotten

out of order and brings sudden and severe strains on the moving parts.

The dynamo should be fastened to a solid base and so compounded that a considerable variation of speed will not cause a very great change in the voltage. Besides this an automatic cut out must be placed in the circuit between the dynamo and the battery, such that when the generator voltage falls to that of the battery, the switch will open and keep the battery from sending current through the dynamo. This switch must also close the circuit when the dynamo voltage rises above the battery voltage, moreover it must work entirely without attention and be positive in its action, as the success of the plant is dependent on the working of this automatic switch.

Where the wind mill is used to pump water into a tank to be used later to run a water-wheel, the system is simplified very much. For this purpose a closely regulating wheel is not required, which permits the use of a cheaper mill. When used for pumping, the windmill patterned after the turbine is most efficient and will run on very little wind, in fact this form of mill will pump water when no air currents can be detected on the ground, hence a scarcity of power is not likely to occur.

In the use of water pumped by a mill it is necessary to provide a large receiving tank of several thousand barrels capacity, for the storage of the water. If this tank can be made by excavating the land on top of a hill, it may be comparatively inexpensive, but where a wooden tank must be built, the expense is too great to warrant such an installation, as the cost exceeds many times the cost of a storage battery.

Pelton wheels are generally used to drive the dynamo, thus giving a very steady supply of electricity so long as the variations in the load are not great. It is plainly seen that either of these systems is applicable to comparatively small plants, probably not more than 50 to 100 lights capacity, and when once installed and well started the expense is very little compared with other methods of obtaining power.

An ideal wind mill electric lighting plant may be designed from the following description: Suppose 25 lights are desired to run on an average of three hours a day in the winter, the

lamps to be 50 volt 10 c. p. This will take a 1½ horse-power dynamo or a 16, 16 c. p. lamp machine, which can be run by a 14 or 16-ft. wheel. The dynamo is to be direct current, differentially compounded, and to run at 2000 R. P. M. at 75 volts and 15 amp. A centrifugal governing geared mill is to be used, and as a closer regulator, a centrifugal ball governor to actuate a shunt field rheostat may be employed to keep the voltage nearer steady, or the governor may be attached to the brush arm to keep the brushes at the neutral point, leaving the speed control to the mill. The dynamo and 25 cells may be placed in a room made by casing the frame of the wind-mill, having two floors—the upper for the generator and the lower for the battery. For a plant of this size the automatic switch should be controlled by an electro magnet, the current to be shunted from the main line and the contacts made in glass mercury cups, as the contacts can be adjusted with less difficulty when in sight, the leading in wires being brought in either from the top or bottom. Mercury is better than other forms of contact makers because it never sticks, a point which is of the greatest value in a plant of this kind.

The wires from the dynamo are carried to the automatic switch and from here to the battery; from the battery the wires may be laid underground to the buildings, and in case the buildings are some distance off an extra cell or two may be added.

A plant of this kind will cost between $300 and $450, not including work, and should give sufficient light the year around where but 25, 10 c. p. lamps are needed. Of course in case of a week's stillness of wind, less lamps should be used, but in the Western Central states where wind is quite plenty, a plant of this description should give good satisfaction with very little attention.

THE RESIDENT ENGINEER.

FRANK H. CONSTANT, C. E.

One of the first positions the young civil engineer may have to fill is that of Resident Engineer. What is this creature? To the lay mind the image is vague and conflicting.

If you were to ask three persons for a definition of civil engineer, there would be three different answers. One would tell you that Washington, as he threaded the pathless forest with tripod over his shoulder to lay out vast tracts of land, was the prototype of the civil engineer, and that his followers are to be found similarly in rough and new countries, enduring privations and experiencing wild and stirring adventures, as they blaze the way for new railroads and the march of civilization. Another would tell you that the civil engineer is primarily a builder. When a bridge is constructed he will speak of it as *his* bridge. It is *his* pier that is founded upon a ledge of limestone that *he* discovered at a depth of thirty seven feet below low water. It is *he* who adopts this expedient for righting *his* tilting caisson, or that expedient to encourage the two halves of his cantiliver bridge to meet in fraternal union over the middle of the river. *He* goes ten feet farther into the solid rock in order to build *his* masonry dam for the centuries to come. He does this; he does that until to the bewildered mind this man seems to be the embodiment of infinite activity and power. He is not necessarily to be found in the wild places of the earth. He is equally in evidence near cities where the wants of modern life are manifold and exacting. Still others will tell you that the civil engineer of their acquaintance complains of the drudgery of perpetual office work. Much of his time is spent in keeping business accounts. He is posted upon market prices; he knows a shipping list or an invoice from a check; he knows the prevailing rates of interest, and has heard of dividends; he knows whether some contemplated project will be profitable or not. He haunts well equipped office buildings and wears clean linen; he is constantly por-

ing over plans or drawings, or writing memoranda in his note books, or entertaining business acquaintances at lunch. After awhile he becomes a general manager of some industrial corporation; or perchance, since there is a sadder side to this picture, he may remain, though fifty years of age, a draftsman with the Slowtown Bridge Co. Surely this description of the civil engineer cannot be consistent with the picture of the adventurous frontiersman! and yet it also is true and is a third side to the shield.

The truth is that civil engineering has developed historically in just the order given above, and this threefold characterization stands for the three classes of civil engineers. What are known as the branches of this somewhat inclusive profession, such as railroad, hydraulic, structural, or municipal engineering, are not more different from one another than are these three types of engineers. These are names for the particular kind of knowledge required, but the training, habits of mind and the methods of applying this knowledge are the same for all. For this reason the young engineer may indifferently choose any one of these specialties for his life work, or pass from one to another. And whether he casts his lot with the field engineer, or chooses to remain within the walls of an office, will affect not only the kind of knowledge which he will acquire but the very springs of his mental and physical life. The field engineer is different from the office engineer and unless he is early trained in both schools the one soon becomes incapacitated for the work of the other.

I consider it highly advisable that the young engineer should get some field experience in the early days of his practical life. Let us call our three classes of engineers the locating, the resident and the designing engineers. A short apprenticeship with a locating party may be sufficient, unless he intends to specialize in railroad work; but several years in resident work, if the construction is varied and interesting, will be an important training for later success. It is here that he gains the mental balance, power and judgment which come from seeing real things as they are, grappling and overcoming real and apparently overwhelming forces, and learning to know and to control men actuated as they are by the common im-

pulses of their kind. Later on, if he can overcome the irresistible charm of free open air life, he will be found more and more constantly in engineering offices, seeking the higher rewards always to be found at the source of things. By this time he is ready to become the designer and ultimately the master, for he has learned by actual experience each detail of execution, every emergency to be provided for, and every difficulty to be overcome.

The order of procedure upon any piece of work is generally invariable. First, the field man to blaze the way; then the office man to design; and finally the resident engineer to execute. I shall confine myself to the duties of the latter.

In the first place it must be understood that the *residence* may be a ten by twelve shack, or the commissary tent of a contractor's camp, or the comfortable quarters of a city hotel. The duties, likewise, may range from the charge of construction of a twenty-story office building, to the bossing of an Irish foreman on a railroad dump. The essential qualities required for either case are not very different, and as the writer comes fresh from the latter job, he will speak definitely of the duties of a resident engineer upon the construction of a new railroad.

When a new railroad is to be constructed parties of locating engineers pass rapidly through the country, locating, after several preliminary trials, the permanent line. This line is marked more or less securely by stakes, wooden hubs, or iron spikes driven into the frozen ground when the survey is made in the winter time. Levels are run over the line at the same time and bench marks are established every four or five hundred feet upon tree stumps or other immovable objects. From the notes obtained by this survey the profile of the line is drawn and the grade lines established. This keg or two of spikes strewn over a few miles of country, a few stumps of trees conspicuously marked "B. M.," a couple of note books, and a copy of the profile map, are the sole heritage of the resident engineer when he arrives on the ground a few weeks later.

Agents of the company follow up the locating party and quietly secure a tract of land on each side of the line, which is thereafter known as the right of way. If this is not done until after the location of the new line is known by the public, the

passing of the right of way man, like the plotting of Mark Twain's "Man who corrupted Hadleyburg," is a severe test of human nature.

The contract for the entire construction of the road is generally given to one man, who sublets the earthwork, the timber work, masonry, track laying and other parts of the work. Soon the arrival of wagons, horses, tools and camping outfits change the peaceful pastoral or woodland scene for one of life and activity. Soon also these stately trees and gentle slopes of the hillside will have disappeared for ever. To the contractor, however, these trees represent a certain number of acres of clearing or grubbing, to be paid for at the next monthly estimate. There is not much sentiment in railroad building.

It is fortunate if the resident engineer can arrive upon the ground before the appearance of the contractor, for there is much preliminary work to be done. Every stroke of work the contractor is to perform will be in some way connected with that significant entity known as the "line." It is the first duty of the resident engineer to jealously preserve this line and to be able at any subsequent time to instantly locate a designated point upon it, and to state the exact difference in elevation between the top of the stake and the true grade line. Inasmuch as several months may have elapsed since the passing of the location party and the spring freshets or the dainty hoof of the wandering cow may have removed or displaced the stakes or spikes, it is the first duty of the engineer to relocate his line and check his bench marks, making slight and unimportant changes here and there, and adjusting all errors, which he may discover, within his own residency so that his troubles may not be unloaded upon the neighboring resident. As the contractor will soon plough up the engineer's stakes, these must be securely referenced to trees or prominent points located off of the part of the right of way liable to be disturbed by the busy operations soon to follow. After this, cross section levels must be taken along the line, and slope stakes set at those places where the contractor desires to begin work.

By this time the scene will be alive with industry. Other contractors will continue to arrive to undertake the several features of the work. Pile driving and the construction of the

wooden bridges will occupy much of the engineer's time. Complete bills must be made for all of the material needed; each pile must be located on the ground and elevations for pile cut-offs given; center points for sills, caps and ties marked; and a constant inspection of the work maintained.

The resident engineer should early make a careful reconnoissance of his residency in order to study the drainage problems and determine the location of culverts, trestles and drainage ditches. If good judgment is not used in this part of the work, he may find that his embankment has become a dam for an artificial lake, a duty it was in no wise intended to perform. Culverts are put in simultaneously with the grading, and need, therefore, to be early staked out and the bills of materials ordered.

The amount and variety of work in a residency will vary manifoldly. The simplest residency will contain earthwork, a few culverts, a wooden bridge or two and possibly a station or two. Such residencies are about fifteen miles long, the great length compensating for the paucity of details. Another residency, perhaps a close nighbor of the preceding one, may contain a great variety of difficult work, but will be correspondingly shorter.

If a residency contains an important steel bridge or viaduct, this work alone will occupy nearly the entire attention of the engineer or of one or two competent assistants. The contractor gives notice that he is about to excavate for the foundations of certain piers. The engineer very accurately locates these piers, referencing his points so that they may be instantly available at any future time. After a time the engineer looks into the hole that has been dug, sounds the bottom, examines the adjacent hillside for possible land slides, goes up the river to see whether a future change in its course may expose the foundation of the pier to the scouring action of the water, compares the elevation of the bottom of the pit with the number of courses of stone in the pier and finally gives the decisive instructions and elevations. From time to time he checks the work of the mason and when the top stone is about to be laid on its bed of mortar he is on hand to give the exact elevation

for the top of the stone. All such caping stones should be laid to the engineer's exact elevations.

The location of the piers should be correct within one-half inch, and if anchor bolts are bedded in the masonry as it is built up, the location of these must be exactly correct. The resident engineer is also the inspector of the work as it progresses. He makes tests of cement, insists upon proper methods of mixing concrete and mortar, sees that the stones are cleaned and wet before being embedded in the structure, and that partly set mortar is scraped off and removed. As the steel work goes up the inspection of the field riveting will demand a large part of one man's time.

Instead of dwelling longer upon the details of the resident engineer's work, it will be more profitable to speak of some of the essential qualities he should possess.

In the first place he should be on terms of easy familiarity with engineering instruments and the methods of field location. Without this his time and attention will be completely occupied with the mere details of instrumental work when he should be engaged with larger engineering and business problems that will rapidly demand attention. In any but the least difficult of residencies, even an expert field man will need a competent assistant to do the instrumental work while he devotes his time to the business problems. But since the resident engineer is responsible for the work of his men he should be able to rapidly and constantly check the more important instrumental results. It is well, therefore, if the young resident engineer may have previously passed an apprenticeship in location work.

A second qualification, without which the resident engineer cannot succeed, is *accuracy*. This is true for all engineers, but perhaps more so for the resident engineer. For in the construction of important structures, costly operations will be based upon the location of a tack head or the elevation of a stake. If a pier, for example, which is to support a long steel bridge, is located a little too far one way or the other, it may have to be taken down and rebuilt—a very costly operation. Sometimes the wrong is irreparable. A few costly errors of this sort may quickly result in the closing of the engineer's profes-

sional career. Since every act of the engineer is fraught with grave consequences, unless he is absolutely sure of his results, the burden of responsibility accumulating upon his shoulders will soon become too great for one man to carry and yet maintain a clear and efficient mind for new emergencies. Aside, therefore, from his mere peace of mind and personal happiness, his efficiency depends upon his faith in the correctness of his work. This certainty can only come by repeated and most careful checks of every phase of the work. The chief engineer of a prominent railroad stated that it had been his custom to check his work in two or three different ways, and then to sit down for an hour to study out still another way in which to check it. Better still if the engineer can make an independent check of the work of a competent assistant, for errors cling most tenaciously to the garments of the same man. Of course the number of checks to be made in any given instance must be determined by good judgment, for a needless repetition results in a mere waste of time and sometimes demoralization when the results do not agree.

A third qualification of great importance is a knowledge of systematic business methods. Business methods are the easiest and quickest way of doing things. Engineering is nothing more or less than the conduct of a large business. If the engineer does not know the simplest business rules, he will soon be hopelessly swamped and will be placed at the mercy of unscrupulous men. The resident engineer should keep a record of everything he does in the field. the notes being jotted down as the work is performed, and afterwards neatly copied into the other books which are properly indexed and in which any record may be found instantly. It is difficult to take too many notes of field operations, provided that they are systematically kept, because much of the field work will soon be covered up and hidden from view, and the engineer's notes will be the only existing record of what has been done and what must be paid for. A copy of each letter which the engineer writes, and of each bill of material which passes through his hands, as well as each letter, telegram, note of instructions, invoice, drawing, or any document whatsoever, which he receives, should be safely filed away for future reference and a mem-

orandum made in a book, reserved for the purpose, of the date of reception of the document and the disposition made of it. Thus nothing should pass through his hands without leaving some record. Beside expediting his own work, he will be saved the annoyance of having to bear the mistakes of others.

A fourth qualification is professional knowledge. This can come only through training and experience, but in time becomes the engineer's chief capital.

The attitude of the engineer toward the contractor is a matter of considerable importance. Some young engineers boast of their ability to bluff those with whom they come in contact. This attitude, though fundamentally wrong, contains a grain of wisdom. Contractors and foremen are not a class of men to appreciate a frank avowal of perplexity on the part of the engineer. They expect the engineer to be sure of himself at all times, and if he is in doubt it is generally best for him to keep that doubt to himself until, at least, he has found a satisfactory solution. Acknowledgment of error or confession of ignorance, while often unavoidable and necessary, have a tendency to diminish the respect of the men whose respect it is of utmost importance that he retain. Of course the young engineer should not undertake anything seriously beyond his powers or experience, but once embarked upon a piece of work he should, as much as possible, rely solely upon his own ability to meet difficult situations, performing his work quietly, keeping his own counsel, and sharing his perplexities as little as possible with others. Of course, innate good sense must be used here as in all things. The prig or self-sufficient man is an abomination, and such a man quickly becomes the laughing stock of his associates. But there is a difference between egotism and self-reliance. When advice is needed, as will often be the case, the young engineer had best obtain it from his immediate superiors, between whom and himself the frankest of relationships should exist.

While the contractors should not thus become the advisors of the engineer, the latter should aim to maintain friendly relations with them, and should appreciate the practical knowledge which many years of experience have brought to them.

The wise young engineer will thus gain much valuable information not found in books.

A last and most important qualification is common honesty, with its twin virtue, moral courage. The engineer is the arbiter between contractor and employer. His notes and estimates are commonly the only basis of compensation to the former. He should be absolutely just, paying the contractor to the last cent everything due him, but firmly opposing every claim that cannot be shown to be genuine or just. Each contractor will present voluminous claims for "extras," based upon extra material furnished, or labor performed. Many of these claims will be for work which should have been performed anyway under a simple interpretation of the specifications, and for which no compensation is due other than that provided in the specifications. Other claims will be for work performed without the authority of the engineer, and in the hope that he will weakly allow them in the end. A just settlement of all such claims will often be a matter of much perplexity, requiring a clear head, a manly courage, and a firm will. It is then that the measure of the respect which the contractor entertains for his engineer will become manifest.

The honesty and courage of the engineer will often be severely tested by the manner in which he reports mishaps in his residency due to errors or over-sights of his own or of his assistants. The inclination to smooth over unpleasant things, or disclaim responsibility for them is very strong in human nature. But the engineer should manfully shoulder whatever responsibility may belong to him, and frankly report all important information to his superiors, when it is manifestly essential that they should be acquainted with it. He should pursue this course even when it is possible to cover up important but unpleasant facts. Not only is this the honest thing to do, but as in all cases of honesty it is also the wisest policy, for it relieves his mind of an unpleasant burden and renders it more efficient for its work. As long as the capacities of a man are as limited as they are, errors of judgment or knowledge will sometimes occur. In this matter, as elsewhere, good sense must be used. A puerile eagerness to report every trifling fact is as discreditable as a failure to report important and far reaching facts.

The writer regrets that the limits of this paper will not allow him to dwell upon the delightful and incidental side of resident work, for there is a delightful side. As he participates in the daily picnic lunch upon the green bank of some cool stream, or listens to the good humored jokes of the working men as he shares their mess in the dining room of a contractor's camp, or as he drives home in the evening across beautiful farming country as the sun is setting over the hills, and but for the tinkling of a distant cow bell or the note of a song sparrow, no sound is to be heard to break the universal peace, except perchance the low murmuring of voices at an occasional camp, or as he is thrown in daily contact with all sorts and conditions of men, and learns to sympathize with and appreciate his fellow men as perhaps never before, the engineer finds an ample recompense in this free, natural life, for all discomforts and cares. It is a pity that it cannot last and that for his best good the man must on to other things.

SECONDARY STRESSES IN FRAMED STRUCTURES.

THOMAS A. CLARK, C. E.

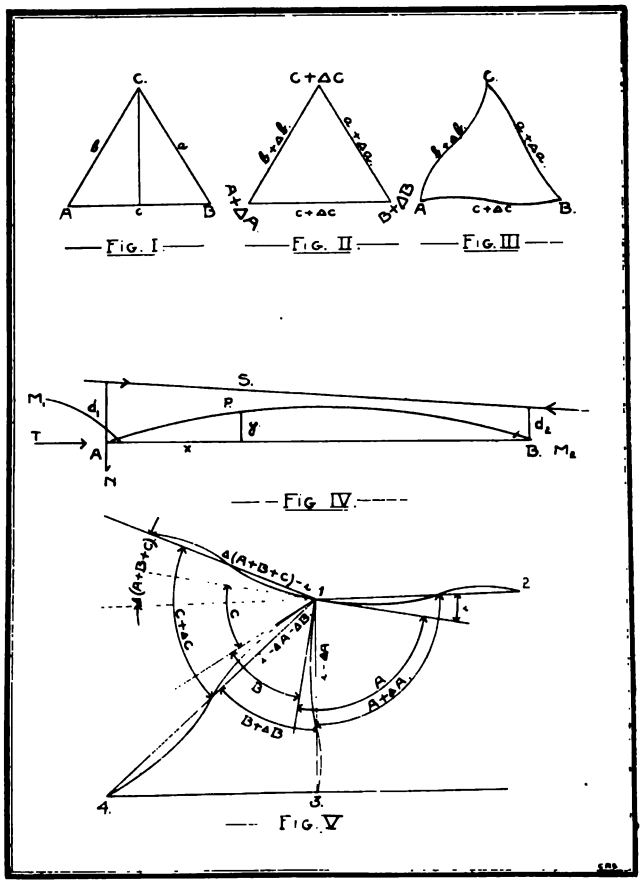
That the forces acting to strain framed structures are little understood seems sufficiently evident when we think of the large factor of safety used in the best designs. Much of the uncertainty lies in the difference between the material that *must* be used and the *theoretical* material used in calculation. This may be largely avoided by testing all material before using. But under the most favorable conditions there will be many unforeseen strains that must be borne by the scape-goat —the factor of safety.

In studying stresses and their strains it may be necessary to employ reasoning and methods that are very impractical, so-called. Nevertheless all accurate practical work is based upon underlying principles derived from theoretical investigations. It becomes a duty, then, at whatever expense of time and patience, to discover the laws governing actual stresses and their strains, though it may be long before practical use will be made of such laws.

The pieces that make up a framed structure are designed to fit forces formed by treating the joints of the structure as frictionless hinges. In the actual structure the pieces are riveted at the joints, or fastened with pins. In the first case the hinge becomes absolutely rigid; in the second it is far from frictionless. When the calculated stress is applied to a piece it changes its length. If the joints were frictionless, the angles between the pieces would change, and the new stresses arising would be easily calculable. But the joints being rigid the pieces must bend in order to make the required change of angle. The stresses arising from this bending are called *secondary stresses.* The original calculated stresses are the *primary stresses.*

Prof. H. Mandula, of München, has made a careful study of secondary stresses. From partial translations of his writings I have collected a few formulas and principles. In the present article I have derived these formulas from principles familiar to all students in strength of materials.

Since framed structures are made up of combinations of triangles, we first study the effects produced by the changes in length of the sides of a triangle.



Suppose the sides of the triangle (Fig. I) to change in length. The angles will then change in size, giving the new triangle (Fig. II). If we apply such forces to the sides of the second triangle as will change the angles to their original values, we will have Fig. III. The secondary stresses are the stresses now arising from the bending moments in the sides of the triangle Fig. III.

The distances between the vertices of the triangle (Fig. III) are not quite $b+\triangle b$, $a+\triangle a$, and $c+\wedge c$; but the difference between the straight line distances and the curved line distances, being extremely small, is neglected.

If we knew the changes in the sides and angles of the triangles we would know what forces to apply to the sides to return the angles to their original values. We can get the increase in the lengths of the sides since we know the primary stresses. We have $E = \frac{\text{unit stess}}{\text{unit strain}} = \frac{\frac{P}{a}}{\frac{\triangle l}{l}}$ where a = area of cross-section; $\wedge l$ = increase in length l of the piece; P is the primary stress and E is the coefficient of elasticity.

$l = \frac{Pl}{aE} = \frac{pl}{E}$ where p is the unit stress. Since it is the change in the angle that we want we must find the changes in the angles of a triangle due to a change in its sides. In any triangle, $c^2 = a^2 + b^2 - 2ab\cos C$.

Differentiating we have

$c\,dc = a\,da + b\,db - b\cos C\,da - a\cos C\,db + ab\sin C\,dC$

$c\,dc = (a - b\cos b)da + (b - a\cos b)db + ab\sin C\,dC$

From Fig. I. $c = b\cos A + a\cos B$

$b = a\cos C + c\cos A$

$a = b\cos C + c\cos B$

$\therefore\ c\cos B = a - b\cos C$

$c\cos A = b - a\cos C$

Hence

$$c\,dc = c\cos B\,da + c\cos A\,db + ab\sin C\,dC$$

$$dC = \frac{c\,dc}{ab\sin C} - \frac{c\cos B\,da}{ab\sin C} - \frac{c\cos A\,db}{ab\sin c}$$

$$dC = \frac{c}{ab}\,\frac{dc}{\sin C} - \frac{c\cos B}{b\sin c}\,\frac{da}{a} - \frac{c\cos A}{a\sin C}\,\frac{db}{b}$$

From the law of sines

$$\frac{c}{ab} = \frac{\sin C}{\sin A\sin B};\ b\sin C = c\sin B;\ a\sin C = c\sin A$$

$$\therefore dC = \frac{\sin c}{\sin A\sin B}\,\frac{dc}{c} - \frac{\cos B}{\sin B}\,\frac{da}{a} - \frac{\cos A}{\sin A}\,\frac{db}{b}$$

$$C = 180 - (A + B). \quad \therefore \sin C = \sin(A + B).$$

$$dC = \frac{\sin A \cos B}{\sin A \sin B}\frac{dc}{c} + \frac{\cos A \sin B}{\sin A \sin B}\frac{dc}{c} - \frac{\cos B}{\sin B}\frac{da}{a} - \frac{\cos A}{\sin A}\frac{db}{b}$$

$$dC = \cot B\left(\frac{dc}{c} - \frac{da}{a}\right) + \cot A\left(\frac{dc}{c} - \frac{db}{b}\right)$$

If p_a, p_b, p_c are the unit stresses in the pieces of length, a, b, and c respectively, we have by the formula $\frac{\Delta l}{l} = \frac{p}{E}$,

$$dC = \left(\frac{p_c}{E} - \frac{p_a}{E}\right)\cot B + \left(\frac{p_c}{E} - \frac{p_b}{E}\right)\cot A$$

If we now regard E as the same throughout the structure, or each triangle considered, we may write for the changes in the three angles

$$\left.\begin{aligned} EdC &= (p_c - p_a)\cot B + (p_c - p_b)\cot A \\ EdB &= (p_b - p_c)\cot A + (p_b - p_c)\cot C \\ EdA &= (p_a - p_b)\cot C + (p_a - p_c)\cot B \end{aligned}\right\} 1.$$

The next problem is to find the equation of the elastic curve for the sides of our triangle. Let the beam, AB, be in compression. Suppose the force S to pass through the central joint points, while the ends of the beam AB do not. Resolving S into T* along and N perpendicular to the beam, we have the following forces and moments at A: T, N, M, and (d_1 s.) As in any good design d_1 and d_2 will be zero, we will neglect the moment ($d_1 s$). We now have at any point P of our beam the moment $Ty + Nx + M_1$. We have, therefore, $EI\frac{d^2y}{dx^2} = -Nx - Ty - M_1$ by a well known formula of moments. The letter I represents moment of inertia.

For a beam in tension we get

$$EI\frac{d^2y}{dx^2} = Nx + Ty - M_1$$

If we write these expressions

$$\frac{d^2y}{dx^2} - t^2y = \frac{N}{EI}x - \frac{M_1}{EI}$$

$$\frac{d^2y}{dx^2} + t^2y = -\frac{N}{EI}x - \frac{M_1}{EI}$$

* T is regarded as equal to the primary stress in the piece.

where $t^2 = \frac{T}{EI}$, we have well known differential equations. Multiply the first by e^{tx} and e^{-tx} and integrate. From the two equations resulting eliminate $\frac{dy}{dx}$ and we have

(2) $EIy = c_1 e^{tx} + c_2 e^{-tx} - \frac{Nx}{t^2} + \frac{M_1}{t^2}$. e is the base in the Naperian system of logarithms. c_3 and c_4 are constants of integration. Multiply the second equation above by $\cos tx$ and $\sin tx$, and, proceeding as before, we get

(3). $EIy = c_3 \sin tx + c_4 \cos tx - \frac{Nx}{t^2} - \frac{M_1}{t^2}$.

Our constants of integration, c_1, c_2, c_3 and c_4 are completely determined since when $x = 0$, $y = 0$ and when $x = l$ $y = 0$. Putting $x = 0$ in equation (2) we have $c_1 + c_2 = -\frac{M_1}{t^2}$. Putting $x = l$ we have $c_1 e^{tl} + c_2 e^{-tl} = \frac{Nl}{t^2} - \frac{M_1}{t^2}$ From these equations we get

$$c_1 = \frac{M_1 e^{-tl} - M_1 + Nl}{t^2 (e^{tl} - e^{-tl})} \qquad c_2 = \frac{M_1 - M_1 e^{tl} - Nl}{t^2 (e^{tl} - e^{-tl})}.$$

In equation (3), putting 0 and l for x and solving for c_3 and c_4 we get

$$c_3 = \frac{Nl - M_1 \cos tl + M_1}{t^2 \sin tl} \qquad c_4 = \frac{M_1}{t^2}$$

Taking the first derivative of (2) and placing $x=0$ and $x=l$ we have the values for the slopes at each end of the beam.

$$EI\frac{dy}{dx} = tc_1 - tc_2 - \frac{N}{t^2} = EI\, i_1$$

$$EI\frac{dy}{dx} = tc_1 e^{tl} - tc_2 e^{-tl} - \frac{N}{t^2} = EI\, i_2$$ where i_1 and i_2 represent the slopes at $x=0$ and $x=l$ respectively. If we now replace the constants c_1 and c_2 by their values and eliminate N between the two slope equations, we get an equation in M_1, i_1 and i_2.

$$M_1 = EIt \frac{tl \coth tl - 1}{tl - 2\tanh \frac{1}{2}tl} i_1 + EIt \frac{1 - tl \operatorname{cosech} tl}{tl - 2\tanh \frac{1}{2}tl} i_2$$

the angular functions being hyperbolic functions. Calling the coefficients of i_1 and i_2 A_1 and B_1 respectively we have

$M_1 = A_1 i_1 + B_1 i_2$

If we had worked from the other end of the beam our forces would have been the same except M_1 and i_1 would now become M_2 and i_2. $M_2 = A_1 i_2 + B_1 i_1$.

Proceeding in the same way with equation (3) we get for the compression beam

$$M_1 = EIt \frac{tl \cot tl - 1}{tl - 2 \tan \frac{1}{2} tl} i_1 + EIt \frac{1 - tl \operatorname{cosec} tl}{tl - 2 \tan \frac{1}{2} tl} i_2$$

$M_1 = A_2 i_1 + B_2 i_2$

$M_2 = A_2 i_2 + B_2 i_1$

We may determine the values for A_1 B_1 A_2 and B_2 exactly by the above forms. But there are no extensive tables for the hyperbolic functions of angles. It is therefore convenient to express the values of A_1 B_1 A_2 and B_2 in rapidly converging series. It is easy to do this first for the forms involving the circular functions of angles. We may then get the series for the hyperbolic functions by replacing x with $\sqrt{-x^2}$; for $\sin h\, x = \frac{\sin \sqrt{-x^2}}{\sqrt{-1}}$; $\cos h\, x = \cos \sqrt{-x^2}$; $\tan h\, x = \frac{\tan \sqrt{-x^2}}{\sqrt{-1}}$ etc.

We get

$$A_1 = \frac{EI}{l}\left\{4 + \frac{2}{15} t^2 l^2 - \frac{11}{6300} t^4 l^4 - - - -\right\}$$

$$B_1 = \frac{EI}{l}\left\{2 - \frac{1}{30} t^2 l^2 + \frac{13}{12600} t^4 l^4 - - - -\right\}$$

$$A_2 = \frac{EI}{l}\left\{4 - \frac{2}{15} t^2 l^2 - \frac{11}{6300} t^4 l^4 - - -\right\}$$

$$B_2 = \frac{EI}{l}\left\{2 + \frac{1}{30} t^2 l^2 + \frac{13}{12600} t^4 l^4 - - -\right\}$$

We have next to determine the values of the angles i and the solutions for M_1 and M_2 become complete. From Figure 5 we see that there is a relation between all of the angles i at any one joint. If, then, we can determine one of the angles i at a joint and know the changes of the angles between the pieces meeting at that joint, we can solve for all of the i angles at the joint. We do know all of the changes in the angles between the pieces meeting at a joint by our formulas (1). We can

therefore get the change in angle between the chord pieces at a joint. This angle was originally 180° say; but for the bottom chord of a roof truss or bridge the angle becomes less than 180°, due to the changes in all the angles of the structure. If we suppose the chords free to move around their joints we can easily plat the position of the joints of a structure after deformation. Now the chords must remain straight at their joints, since they are not actually free to turn. If we could get the curve upon which the joint points lie, the tangent to the curve at that point would be the direction of the chord at that joint. Knowing the angle that the chord pieces have if free to move around their joint : and knowing the actual direction of the chord at that joint, we know through what angle we must bend each chord piece to force it from the hinged joint position to the actual position for rigid joints. Hence we have two i angles at a joint, and the remaining i angles may be determined for that joint.

For chords of uniform strength, the theoretical curve upon which the joints lie, is a circle. In this case the angles i are easily determined. From a theoretical standpoint this is, perhaps the most important case. We may take our formulas

$$EdC = (p_c - p_a)\cot B + (p_c - p_b)\cot A$$
$$EdB = (p_b - p_c)\cot A + (p_b - p_a)\cot C$$
$$EdA = (p_a - p_b)\cot C + (p_a - p_c)\cot B$$

using for p_a p_b and p_c the unit stresses chosen according to the material used and the kind of stress in the member. Making our pieces of uniform strength, we easily get the i angles as the chord joints will lie on a circle. From the values M_1 and M_2, we get the secondary stresses in the members and thus learn the proportion they bear to the theoretical primary stresses.

PHOTOGRAPHY.

W. R. HOAG.

Since the time Daguerre first announced his discovery in 1840 of the processes by which he was able, through the direct action of light upon a sensitized plate, to produce a permanent perspective image of objects, the world has been eager to apply this new science in whatever way it could be made to serve a practical end or even please the fancy.

The practical application of photography to all lines of engineering has kept pace with the science itself. Each advance in simplification of instruments and processes, and each reduction in cost, has been accompanied by a corresponding increase in the field of its operation.

Upon the introduction of the dry-plate the advance became very marked. As a ready means to accurate and inexpensive illustration it is used with nearly equal advantage by each of the engineering professions. The electrical and mechanical engineer employs photography in presenting details of machinery and apparatus, either through the medium of lantern slides or by prints furnished by the manufacturer to would-be purchasers.

The mining engineer employs the simple illustrative feature of photography in showing systems of timbering in mines, etc. The landscape engineer uses photography with great effect in presenting the general results to be gained by some proposed improvement. Civil engineering comprehending a somewhat wider range of operations with larger structures, such as bridges, locks and dams, viaducts, etc., makes very extensive use of photography as an illustrative art, especially in making reports of progress.

By means of this science and the process of making halftone illustrations, the world at large is gaining an interest and knowledge in engineering works which would otherwise be impossible. Besides the uses of photography as a mere illustrative art the civil engineer employs it to the fullest extent of its development as an exact science. By its aid he

makes pictures, not for their beauty nor yet to show how objects appear when viewed from a certain point, but rather, to get certain definite information as to where the objects really are, relative to each other and the observers' station. With this information he is able to make as accurate a topographic map of the territory in view, as with data from a much more expensive survey with the ordinary instruments.

Though the method of making a topographic map from a perspective sketch was fully elaborated by Laussedat in 1850, it was some time before the methods of photography were sufficiently perfected and simplified as to replace the camera lucida, which was at first employed. Since then great advances have been made in the practical application of the science. We find successful experimenters with this applied science in Germany—among them being Meydenbauer, Jordan, Koppe and others. In Italy the celebrated engineer Porro and Lieutenant Michele each contributed elaborate though somewhat visionary schemes of employing photography, which were not favorably received by the profession. The present ordinance photographic survey of Italy is progressing rapidly and valuable contributions are being made to the practical science. Since 1869, photogrammetry, as it is there called, has formed a regular part of the lecture and practice work at the Royal Building Academy in Berlin and later at the Royal Technical High School in Charlottenberg.

Some of the most successful applications of photography to surveying have been made by the Austrian engineers and their instrument makers have constructed a large variety of surveying cameras.

In the United States comparatively little has yet been done either to advance the science or to apply what has already been proven to be of economic worth. The little done in this country was done by the United States Lake Survey in its topographic work about Sault Ste Marie. In Canada the most successful application has been made of photographic surveying. In 1892, 2,000 square miles in the vicinity of the Canadian Pacific Railway were thus mapped, and in 1893 and 1894 the International Boundary Commission surveyed

about 14,000 square miles along the boundary between Canada and the United States Territory of Alaska.

From these conspicuous cases of the extensive and successful application of photography to surveying numerous other less important instances might be given.

The camera, to the Civil Engineer, is not a mere picture-machine, whose product is to be looked at, but rises to the dignity of a scientific instrument by whose magic a piece of topography is to be gathered in, preserved, and at pleasure made to reappear in a perfect topographic map.

In photogrammetry we select certain controlling points in nature, and, just as in the plane-table or stated methods, observe from them; measuring the horizontal and vertical angles to other points. We can identify these points on the photograph, and by graphical construction—reversing the processes of perspective—produce, to any desired scale, an orthographic map of the area included in the photograph.

To become a successful operator in photography one needs all the instincts of the reconnoitering engineer, coupled with a good foundation knowledge in optics, descriptive geometry, perspective, photo-chemical analysis and cartography. Its slow adoption by the profession is due to these latter requirements.

When we have engineers fully equipped with this fundamental knowledge we shall see its general application where rapid economical surveys are to be made to secure maps of moderate precision.

It is not within the possibilities of this brief article to give even the fundamental principles of Iconometry, the science of changing the perspective view into the orthographic drawing. It differs in method from the science of perspective only by being the exact reverse. The reader is referred to such works as "La Fototopographia in Itatia," L. P. Paganini, 1889; "Comptes Rendus de l'Academie des Sciences," Paris; "Revue Scientifique," 1894; "Die Phothgraphische Messkunst," Prof. Franz Schiffner, 1892; "Photography Applied to Surveying," Lieut. Henry A. Reed, U. S. A., 1889. "Photographic Surveying," E. Deville, Ottawa, 1895.

THE NEW MECHANICAL ENGINEERING SHOPS OF THE UNIVERSITY OF MINNESOTA.

J. J. FLATHER.

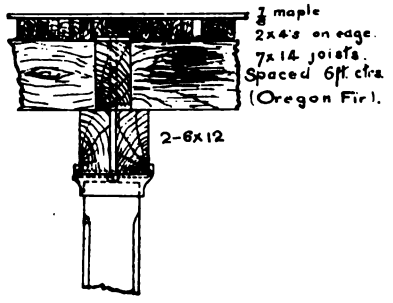
Sixteen years ago, when the present Mechanic Arts Building was erected, not only was the entire work of the engineering department carried on in this building, but the department of physics was also located within its walls. Since that time many changes have occurred. Numerous additions have been made to the original building; the attic has been finished off for drawing rooms, the engineering laboratory has been extended, and an annex containing forge shop and foundry has been erected: yet, with all these enlargements, it has been apparent for some time that the present quarters are totally inadequate for the needs of the College.

The department of electrical engineering is temporarily located in the Chemistry Building, and the work in Applied Mechanics is administered in still another building where rooms are found large enough for the present classes. To meet these conditions, and the more closely unify the interest of the department of mechanical and electrical engineering, a new Engineering Building has been planned which when completed will contain the various shops and laboratories of both departments as well as lecture, recitation, and drawing rooms for the work of the junior and senior years.

The building as planned consists of a main front connected to two wings one of which will contain the mechanical and electrical laboratories, the other the shops.

In order to give present relief to the over-crowded Mechanic Arts Building, the last legislature appropriated a sum of money wherewith to erect the shop wing of the Engineering Building. This wing, the floor plan of which is shown in Fig. 1, will consist of a two-story portion containing the machine shop on the first floor and the wood shop on the second; beyond the machine shop and at a different level is the forge shop and foundry, both one story in height. This wing, when completed, will occupy a ground area of 47x235 feet, with an

18x50 ft. addition to the foundry. It is intended that these shops shall contain the best features of modern commercial work-shops, and it is believed that they will have a certain educational value in this respect. Slow-burning mill construction will be used throughout. This consists of brick walls and heavy timbers which, in case of fire, burn slowly and are safer than the ordinary iron and timber combination for this class of buildings. An interesting feature is the construction of the floors, shown in the above figure. This is practically free from vibration, and gives a very solid foundation for the machinery.



In the machine room a 3-ton traveling crane will cover a clear span of 12 feet the entire length of the shop, thus giving ample space for erecting. This crane will also serve some of the larger machine tools. The benches on each side of the shop will be of 3-inch maple carried on specially designed cast iron legs—a modification of the Brown & Sharp style. The blacksmith shop will contain 20 forges, and will have ample room for the present drop hammer, as well as a power hammer to be added later.

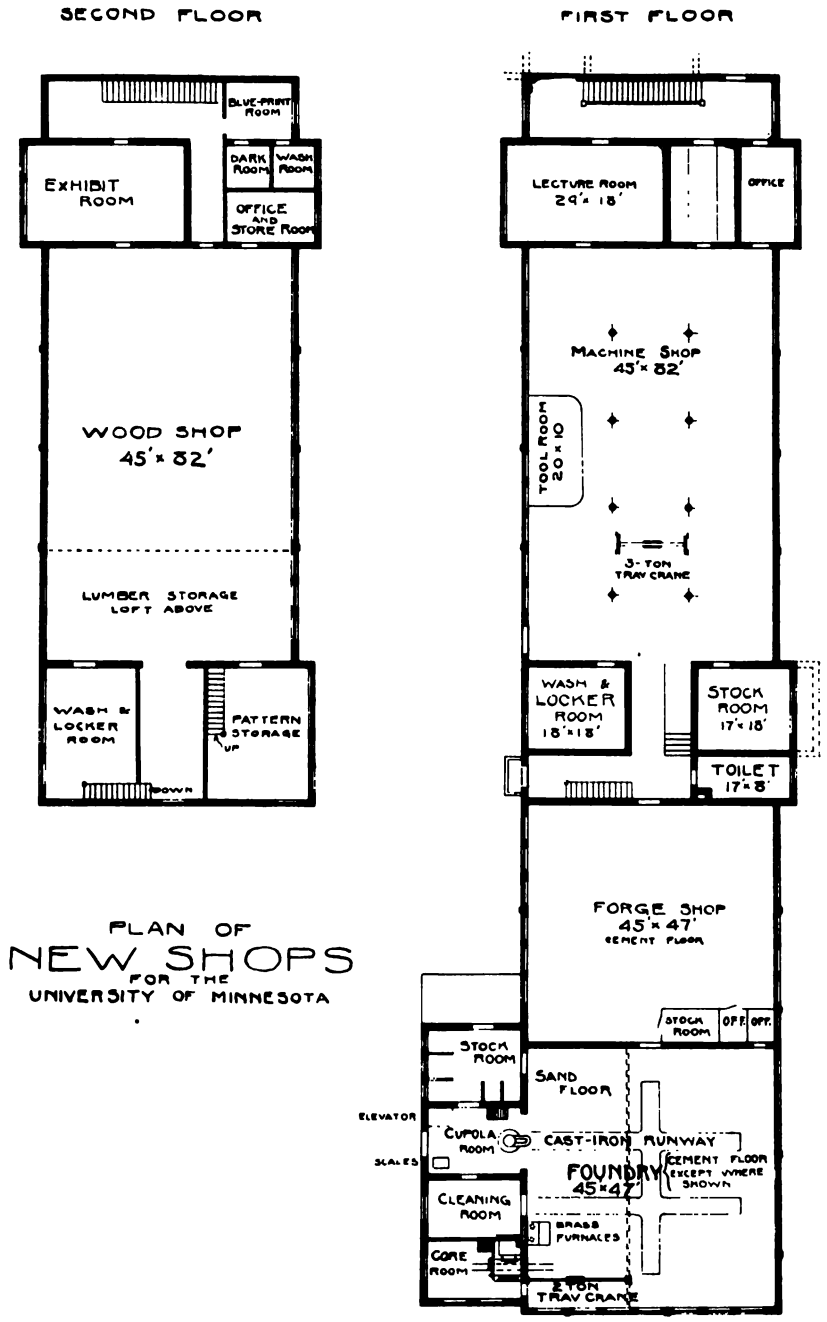
In a college shop the foundry usually receives the least attention, and yet there is no part of a works which will repay careful attention to details more than this department. In the present case the foundry has been the subject of especial study and possesses many features of interest and value. In accordance with best modern practice for light work the floor is to be cemented (except in one section as shown) and the gangways, leading from the cupola and extending lengthwise of the room, are to be of heavy iron plates set in cement. Two brass furnaces are to be provided, embodying some novel features. There are two core ovens; one for ordinary work 3½x3½x5 feet, and one 3½x7x6 feet for special cores which may be required. The feature of these core ovens is that the gases and products of combustion are caused to traverse suitable conduits under a

plate floor and do not come into direct contact with the cores. A light traveling crane is also provided for the foundry. This has a span of 15 feet and a run of 47 feet, the entire length of the room.

The lighting, heating and ventilation of the building has received careful consideration. In the machine and pattern shops 60 per cent. of the wall space above the benches is in glass. In the foundry and forge shop less side light is allowed, since an abundant supply of overhead light is obtained from windows placed in a lantern or ventilator which extends the entire length of the roof. Pipe coils will be employed in heating the building and these will be placed partly on the side walls under the windows and partly overhead.

Electric power will be used for driving the machinery. The group system has been selected as best adapted to the conditions, and a number of small motors will be placed in the several departments. 220-volt continuous current motors will be employed in connection with a three-wire system of distribution, which will also be used for the lighting circuit.

While these are not as large as many of the college shops of the country it is believed that in arrangement, convenience and adaptability to the purposes of instruction they are superior to any.



PLAN OF

NEW SHOPS

FOR THE

UNIVERSITY OF MINNESOTA

TRAIN RESISTANCES.

LESTER DANIEL.

The subject of train resistances is one that has occupied the attention of technical and practical men ever since the introduction of the locomotive, and previous to that time experiments along a similar line had been made by scientific men in Europe, upon rolling and axle friction of common road vehicles; but in spite of the long line of experimentation in this one direction, much uncertainty still exists, results and formulae differing so widely that almost any result, within reasonable limits, can be found. Some claim that the resistances vary with the square of the velocity, others with the first power of the velocity, still others with both the first and second powers of the velocity, while still another finds it to vary with the one and eight tenths (1.8) power of the velocity, and the co-efficients are all at variance, even in equations having the same general form; so that railroad companies, at present, have their own dynamometer cars and obtain results which strictly apply to their road and service only. Even this is not entirely satisfactory, for results obtained under conditions apparently the same, frequently differ widely. It must not be supposed that because results are different, that the tests are poorly conducted, or that there is no law governing such resistances, but it must be understood that tests are made under various conditions, and until standard conditions are prescribed and followed, uniform results cannot be expected. While all tests cannot, perhaps, be made under these exact conditions, nevertheless results might be readily reduced to them since all the laws of physics and mechanics affecting their change are thoroughly established.

In calm weather and on a straight and level track the energy required to haul a train is absorbed in overcoming rolling, axle and air friction, and is such as to require, at ten miles per hour, about six pounds pull for every ton's weight; at higher speeds this increases, and at thirty miles per hour requires

about ten pounds per ton, at sixty miles per hour, about sixteen pounds per ton [Eng. News '88, page 410]. Laws governing the sliding friction state it to be independent of the velocity and extent of the rubbing surface. [Church's Mechanics, page 165]. Supposing this to be the case, the increasing pull at higher speeds, must then be due to some cause other than axle and air friction; rolling friction is generally considered independent of velocity and Church's Mech., page 187, gives the formula $P = \frac{b}{r} G$ when P is a horizontal force necessary to preserve uniform motion; b is an experimental co-efficient equal to .02; G equals the weight on the wheel; and r equals the radius of the wheel; the expression containing no speed factor. Applying this equation a result of two pounds pull per ton is obtained for railroad practice. Assuming this to be correct at ten miles per hour we have left four pounds per ton for axle and unknown resistances; about 4 lbs. is absorbed in overcoming axle friction. At sixty miles per hour, 16—6 lbs. or 10 lbs.—62% of the total resistance—remains unaccounted for.

This unknown resistance some investigators have assigned to "oscillating and concussion" resistances, but it is difficult to see how the pounding and oscillating of a moving train can absorb so much energy.

It is a matter of every day observation that there is more pounding and oscillating in a fast than in a slow moving train; or in other words that oscillation and concussion increase with the speed. This would require power in just the right proportion, if such motions demanded extra power; but why they should, is not at all clear. Every half oscillation requires a force, which force is given out during the other half; and every action in form of concussion tending to absorb power has an equal and opposite reaction tending to return that power so that at the end of the cycle there is but little loss, theoretically none. Some ascribe this unknown resistance to an "elastic wave" rolling up on the rail in front of the car wheel, and tending to retard its progress. But whatever causes it, it is there, experiment after experiment demonstrates it, and that is enough for the practical man, he knows how

much it is and makes provisions for it without inquiring further.

The Lake Shore and Michigan Southern in 1873, figured that seven hundred and eighty-five thousand dollars ($785,000) a year could be saved by reducing train resistances twenty-five per cent, but it is obviously impossible to effect such a saving without some inquiry into the whereabouts of these unknown resistances. The friction due to air on the sides and top of cars is very small; requiring a pull of 4.2 pound per car [T. A. S. C. E. 1879, page 42], and is a case of sliding friction independent of velocity. Assuming a loaded freight car to weigh thirty-three tons, this air friction amounts to .13 pounds per ton. Variations in temperature seem to affect the resistance in a marked manner.

The "Proceedings" of the Western Railway Club, Feb. 1900, vol 12, page 253; cites an instance where a rise in temperature lowered the resistance twenty-four per cent. The same article also relates a case where a train of empty cars pulled harder than a train of loaded cars, by seven per cent per every ton's weight. Curves also cause a greater draw bar pull; a test made by the Soo Road, Jan. 14, 1900, between St. Croix River and Pennington, Wis., showed this to be quite a factor. If a curve is compensated for a certain speed, a train will evidently round it at that speed without any increased resistance; but at speeds above or below that for which the curve is compensated, increased effort will be required; flexible head couplers and swing beam trucks would in all probability reduce this effort. Side winds greatly increase the retardation of a train; an increase of 60% per ton being found during the C. B. & Q. R. R. tests [Eng. News, 1888, p. 409] while a strong opposing or a strong favoring wind made a barely discernable difference. The above formula for rolling friction indicates that it varies inversely as the radius of the wheel. Further experiments with the above factors composing train resistance, as well as experiments on train resistance in total are needed. An experiment for the latter was made with a dynamometer car by the Soo R. R. last winter with the following results.

No.	Pull in lbs.	Mile Post	Grade in ft. to the mi.	Resistance in lbs per ton	mi. per hour	Remarks
1	24,000	44	42	5.16	6.5	
2	25,000	45	42	6.05	5.8	
3	25,500	48	28	11.8	2.	All cars on 4°
4	25,750	48.59	42	6.66	4.1	curve
5	11,000	59.5	level	9.66	15.3	
6	11,750	68	7.67	7.41	19.8	
7	8,200	70.25	level	7.2	20.5	
8	5,700	89.75	"	5.01	26.5	
9	8,100	92.31	"	7.11	22.	
10	24,200	102.32	42	5.35	8.1	
11	28,000	103.4	42.2	8.6	4.9	
12	11,250	109.5	3.69	8.5	19.2	
13	6,900	118.66	level	5.41	24.4	
14	7,200	126.4	"	5.64	26.	
15	24,250	133.19	42.2	4.76	8.	
16	19,100	133.49	29	3.92	9.5	
17	7,400	136.62	level	5.8	24.7	
18	10,500	141.11	5.28	6.26	20.	
19	15,100	146.63	14.72	6.25	17.	

The train consisted of thirty-five cars with a total weight of 1139 tons—tare 474 tons, merchandise 665 tons. At Weyerhauser (mile post 114) the train was increased to thirty-nine cars, 1277 tons. The thermometer stood 15° above zero, wind very light. Results were deduced from the draw-bar pull P and the grade G by the following relation:

$$\text{Work per mile} = P \times 5280 = R_f \times 5280 + 2000\,GT$$

where the work is expressed in foot-pounds and T is the total load hauled in tons, and R_f is the total rolling, axle, air and unknown resistances combined, and expressed in pounds, this becomes

$$R_f = P - \frac{200GT}{525}$$

Dividing this by the tons hauled gives the resistance in pounds per ton as tabulated in column 5. These correspond closely to the formula $R = 5.25 + .072\,M$ where R is the resistance in pounds per ton and M is the miles per hour. As can be seen the run was made with a freight train and with a small range of velocities 2 to 27 miles per hr.

The following formula proposed by J. B. Blood in St. Ry. Jour. Vol. XIV p 142, gives excellent results through a large range of velocities $R = 4 + .15\,M + .3\frac{M^{1.8}}{T}$

This formula Prof. Flather gives a high place among those proposed by emineut investigators among which are:

Rankine,..... $R = 2.65 + .27\ M$

Clark, 1854,..... $R = 7.14 + .006\ M$

Baldwin Locomotive Works, $R = \frac{M}{6} + 3$

Searles,..... $R = 4.82 + .005\ M^2 + .6\ \frac{M^2}{T}$

Welkner,..... $R = 6.25 + .004\ M^2$

Eastern Ry., France, 1885, $R = 3.6 + .258\ M + .29\ \frac{M^2}{T}$

Wellington,..... $R = 4 + .005\ M^2 + .46\frac{M^2}{T}$

Eng. News, 1893,..... $R = 2 + .25\ M$

Barnes,..... $R = 4 + .16\ M$

Dodd,..... $R = 7 + .20\ M$

Lundie,..... $R = 4 + .20\ M + \frac{14\ M}{35 + T}$

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PRESSURE AND POWER REQUIRED TO ROLL SHEET METAL.

W. P. RICHARDSON and E. K. WENNERLUND.

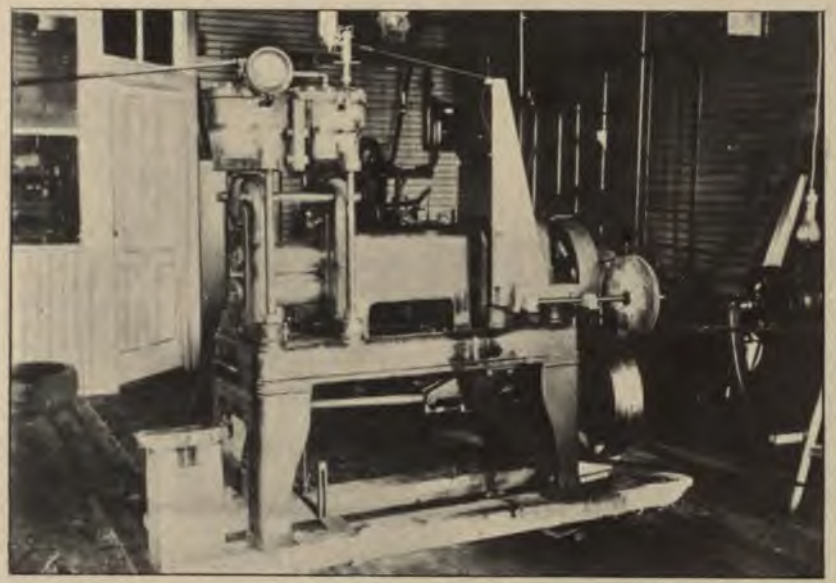
In late years the cold working of metals has become so common and such favorable results have been secured, that the process has received the attention of manufacturers and engineers to a marked degree. Materials so prepared have been found, both in practice and in severe testing, to be greatly improved in strength, ductility and elasticity.

It seems, then, that in that class of machinery, instruments, hardware and manufactures where the material must be of the highest grade obtainable, cold worked metal is destined to come more and more into general use. In reducing metals by cold rolling varying pressures have been used, depending upon the metal employed, and corresponding differences of horse power have been required to operate the rolling mill, but judging from the lack of data on the subject, apparently no means have hitherto been employed to ascertain either the pressures or the power required in this process. It is therefore the object of these experiments:

1st To determine the pressure required to reduce various metals by cold rolling; and to measure the power absorbed by the rolling-mill.

2nd To measure the difference in this power when the rolls are provided with roller-bearings in place of the ordinary bronze bearings.

In order to cover as wide a range as possible it was decided to carry out these experiments with different materials, and with this object in view, samples of mild steel, brass, copper and bronze were obtained. The plan of these experiments included subjecting these metals to various pressures, and after each passed through the rolls, the reduction in thickness, the change in length and width, and the power absorbed by the rolling-mill were determined. After carrying out these experi-



THE ROLLING MILL

SHOWING PRESSURE CYLINERS AND INDICATOR RIGGING

ments, as outlined, with plain bronze bearings, a duplicate set under similiar conditions was performed with roller bearings.

For the above purpose a rolling-mill was obtained from the Mossberg & Granville Manufacturing Co., of Providence, R. I., and a Flather dynamometer was secured for measuring the horse-power absorbed in operating the mill. It was necessary in order to measure the pressure on the rolls, to make some modifications of the rolling-mill. Two cylinders with plungers were therefore placed above the rolls and the necessary connections made for hydraulic pressure. An indicator and hydraulic pressure gauge were fitted to the cylinders so that the pressure per square inch exerted by the fluid could at any time be determined. Cylinder oil was found to be more satisfactory than water in maintaining the higher pressures and was therefore used throughout the experiments. The machine in detail was a No. 4 rolling-mill of the standard type of geared mill built by the Mossberg & Granville Manufacturing Co. The following data obtained from the machine will give a general idea of its size and capacity: Net weight, 3000 lbs.; ratio of gearing 16 to 1; driving pulley, 24-in. diam., 6-in face; rolls, 5-in. diam. 8-in. long; speed of driving pulley, 224 R. P. M.; velocity of belt, 1400 ft. per minute; speed of rolls, 14 R. P. M.; linear velocity of rolls, 18½ ft. per minute. The machine was provided with cut gears throughout and ran smoothly and noiselessly, and during the tests no tendency to overheating was observed. The mill was thrown into operation by a friction clutch which permitted absolute control.

Considering the size of the metal to be rolled it was estimated that a pressure of 50,000 lbs. as a maximum would give the desired results. The compression screws were removed from the rolls, and two hydraulic cylinders were mounted upon the housings of the rolls as shown in the illustration. The plungers of the pistons passed through the holes formerly occupied by the screws and bore upon the tops of the boxes. The distance between the housings being only 12½ inches the size of the cylinders was somewhat restricted and it was found convenient to make them eight inches in diameter, giving an area of piston of practically fifty square inches. The cylinders were connected by a half inch pipe screwed into the covers. From a

T in this connection, a half inch pipe led to a small hand pump for introducing the oil. The pipe connecting the cylinders to the pump was provided with a stop valve close to the cylinders and a drain valve for regulating the pressure between the stop valve and the cylinders. A hole was drilled in the side of each cylinder above the piston and tapped for a half-inch pipe, a gauge being attached to one cylinder and an indicator to the other. Heavy cylinder oil being used to transmit the pressure to the cylinders, it was deemed advisable to fill the pipe immediately below the indicator with light machine oil to eliminate as far as possible the effect of viscosity upon the indicator piston. No indicator permitting a pressure of 500 lbs. per square inch being available, a Thompson indicator having a 100 lb spring was modified to obtain the desired result. This modification consisted of a separate cylinder screwed below the indicator and having a piston area of only ¼ square inch, the plunger of this piston pressing upward against the indicator piston.

The Flather dynamometer used is of the improved type and is fully described in Prof. Flather's book on "Dynamometers and the measurement of Power" a new and enlarged edition of which has just been published. It is sufficient here to say that this dynamometer is the most successful design yet produced and will give, even in the hands of inexperienced observers, valuable results. The machine used was designed to transmit fifteen H. P. During the test the powers measured were not over ten H.P.

The details of the experiment are as follows: Samples of mild steel, brass, copper and bronze of suitable dimensions were obtained, varying in thickness according to commercial sizes. These were cut to about 2 inches wide by twelve inches long. Each strip of metal before being placed in the rolls was carefully calipered for thickness and width to the nearest thousandth of an inch and the length measured to the nearest eighth of an inch. More accurate measurements of lengths could not conveniently be obtained as the strips would in most cases be slightly warped or curled in rolling. Wooden wedges were inserted between the rolls in order to get them sufficiently separated for the metal strip to be placed in position, i. e., with one end projecting about ½ inch beyond the line of centers of

the rolls. The wedges were then withdrawn and the desired gauge pressure applied by means of the hydraulic pump. The indicators on the cylinders and dynamometer were adjusted and the rolls started. In the latter part of the experiments it was found convenient to pass the metal strip through the mill twice before taking measurements, although indicator cards were taken both from the cylinders and dynamometer during each pass. After rolling the second time the reduction in thickness and the changes in other dimensions were measured; then the strip was again inserted between the rolls. This process was, in general, repeated three times (making six passes through the rolls) at each pressure, after which the metal was annealed and rolled at a higher pressure. The mild steel was pickled in dilute sulphuric acid after annealing, in order to remove the scale. Initial gauge pressures in the cylinders of 100, 200, 400 and 500 lbs. per square inch, corresponding to pressures of 10,000, 20,000, 40,000 and 50,000 lbs. on the rolls were applied for each sample of metal. When roller bearings were substituted the main object was to measure the power absorbed. The strips of metal were therefore not calipered, but were rolled six times in succession before being annealed. A series of indicator diagrams being taken from the cylinders, to measure the average pressure; and individual cards were taken from the dynamometer as in the previous experiments.

More uniform results might have been obtained had fresh strips of metal been available after rolling at a given pressure. On account of the limited supply of material it was necessary to anneal and re-roll the same sample a number of times: and the few irregularities are doubtless due to irregularities in annealing. Some difficulty was experienced in keeping the thinner strips on the rolls under high pressure. Unless they were placed exactly in the center of the rolls, the strips would slip toward the side. This caused them to become warped and curved, making exact measurements of length impracticable. The pressure was observed to fall in every case of this kind; probably because the plunger having the greatest leverage, when the strip was near one end of the rolls, would push the rolls together at that end and the other end of the rolls would be raised but little. When the strips to be rolled were $\frac{1}{8}$ inch

or over in thickness, less difficulty was found in keeping them on the rolls.

The use of roller instead of bronze bearings for the journals of the rolls, gives in every case a notable reduction in the horse-power required to operate the machine under different pressures. Some of the dynamometer diagrams, when low pressures were used, indicated so small a horse-power that they were not considered accurate and were omitted from the log of the test. The horse-power required to operate the rolling-mill when running empty was obtained by using smaller cylinders on the dynamometer.

Manufacturers have in some cases been inconvenienced when using bronze bearings on account of heating of the journals. The Brown & Sharp Mfg. Co. report a case in their factory where a six inch belt in connection with a four inch rider was required to run a rolling mill for cold rolling metals. The friction was so great as to necessitate the stopping of the rolls several hours each day, to prevent overheating. Roller bearings were substituted and the mill was run with only a one inch belt and was operated all day without perceptible heating.

The claims of the manufacturers to the effect that roller bearings will decrease the coefficient of friction at least 50% seem to be fully corroborated by the results of our experiments.

It was noticed that the flow of metal during rolling was almost entirely in a direction perpendicular to the axis of the roller; the increase in width being inappreciable. Another interesting point developed was that the horse-power required to drive the rolling mill decreased with successive passes of the metal through the rolls, and was less with steel than with softer metals. The following conclusions were drawn from the results of the tests.

1. For a metal of given hardness the reduction in thickness is proportional to the pressure applied.

2. With a given constant pressure, the reduction decreases with the number of times the metal is passed through the rolls without annealing.

3. The flow of metal occurs in the direction in which the piece is passed through the rolls.

4. The increase in width is negligible in comparison with the change in length and thickness.

5. The horse-power is proportional to the reduction and not to the pressure.

6. With a given pressure the horse-power is in inverse ratio to the hardness of the metal.

7. The average relative efficiency of roller bearings as compared with that of plain bronze bearings as determined by these tests is 3.22 to 1.

[The above is an extract from the Thesis which took the Gillette-Herzog $50 prize in 1899. Ed.]

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MAY, 1901

CARBORUNDUM.

L. J. GRAY.

Less than ten years ago Mr. E. G. Acheson was engaged in some experiments having for an object the artificial production of crystallized carbon. At the conclusion of one of the experiments he observed a few bright blue crystals clinging to one of the electrodes of his improvised furnace. These were at first supposed to be crystals of pure carbon, but further investigation showed this to be impossible, and it was then concluded that they were some compound of aluminum and carbon, for his first mixture contained a considerable quantity of clay. A name was adopted suggesting this supposed composition—carborundum,—a word formed by combining "carbon" with "corundum," the latter being one of the common forms of alumina most nearly approaching carborundum in hardness. Subsequently a chemical analysis revealed the fact that a hitherto unknown substance had been produced. Its constituents were carbon and silicon, united in the proportions of the atomic weights of the two elements, which proved that it was a true chemical compound, the carbide of silicon.

The remarkable physical properties of these crystals at first engrossed the entire attention of the discoverer, and the possibilities latent in the new substance as a chemical reagent were overlooked. The crystals were found to be intensely hard—as hard as diamonds—quite brittle, absolutely infusible, and insoluble in all ordinary solvents, acids having no effect upon them. It was at once realized that these were the characteristics of an ideal abrasive, and that if the substance could be produced on a large scale it would possess a very great commercial value. It was apparent, too, that the word carborundum, formed upon

a mistaken hypothesis and thus misleading, had a happy significance. At that time the best abrasive known was the mineral corundum, next to the diamond the hardest substance found in nature. As carbide of silicon exceeded corundum in hardness, and carbon, an element not present in any of the natural minerals used as abrasives, was one of its two constituents, the combination of the two names suggested at once the similarity in physical characteristics and the difference in chemical composition.

Mr. Acheson is here given entire credit for the discovery of carborundum, and rightfully so. It is true that in the year 1886 the Messrs. Cowles, early investigators in the field of electro-metallurgy produced some specimens of carborundum in the course of their experiments. They did not, however, realize that a discovery of importance had been made, and did not succeed in obtaining a correct analysis. A few crystals were sent to museums as curiosities, labeled either "crystalline silicon" or "silicon monoxide." There they were forgotten until years after, when they were resurrected to be offered as evidence in a patent suit. Mr. Acheson had no knowledge of these early experiments until carborundum had been brought by him into extensive use in the arts.

The first carborundum furnace consisted of an iron bowl lined with carbon, and a carbon rod; a mixture of clay and carbon was introduced into the bowl, and the rod placed in the mixture. A current sufficient to fuse the mixture, or at least to bring it to a very high temperature, was then passed through the furnace, the iron bowl and carbon rod serving as terminals or electrodes.

The furnaces constructed after this experiment approached more nearly in form the furnaces in use today. They were built of brick, their internal dimensions being 10 inches in length, 4 inches in width, and 4 inches in depth. The terminals were a pair of carbons, which could be moved longitudinally, thus permitting the distance between them to be altered at pleasure. These were essentially arc furnaces, that is to say, the idea was to form an arc between the terminals and to bring about the necessary chemical changes by the high temperature thus produced. Mr. Acheson soon found, however, that this method of working was not satisfactory, and he then set about constructing the incandescent furnace, which is the kind that is used today.

For this purpose he introduced into his furnace a core consisting of granulated coke, which formed a continuous electrical connection between the carbon terminals. By adjusting the diameter of the core to the proper size, it was heated to a sufficiently high temperature by the passage of the current to convert the surrounding mixture into carborundum.

Having observed that the amount and quality of the carborundum produced depended rather upon the silica present than upon the alumina, a good glass sand was substituted for the clay in the mixture. It was

also found that the addition of a little salt to the mixture facilitated the running of the furnaces. Some trouble was experienced from the gasses formed during the running of a furnace, and to lessen this, sawdust was added to the mixture to render it porous, and allow the free escape of the gas. The output of these small furnaces amounted to about one-fourth pound per day.

From this time forward the development of the manufacture of carborundum has consisted chiefly in improvements in details of apparatus and operating methods, to bring the cost of production down to a point which makes it commercially available.

The crude materials from which carborundum is made are essentially only coke and sand. The mixture charged into the furnaces consists of coke, sand, sawdust and salt, the two latter substances being introduced for reasons indicated above. A good quality of blast-furnace coke is used, and the sand is necessarily a very pure variety, analyzing at least 99 per cent. silica. The coke is finely ground and thoroughly mixed with the other materials in proportions determined partly by theoretical considerations and partly by experiment. This mixture is then ready to charge in the furnaces.

These are unique, and one who had not seen them in operation would scarcely think the name appropriate. They consist of two heads, or ends, built of fire-brick, about six feet high, eight feet wide, and three feet thick, with a space at the center, a number of carbon blocks, extending through them in the direction of the length of the furnace, and securely clamped outside in iron castings together with metal connections for the electrical conductors. The heads are connected by two walls of loose fire-brick, so that there is formed a large open box, having the heads for ends, the walls for sides, and the floor for a bottom, with no top, sixteen feet long, six feet wide and six feet high. This box is filled to the top of the walls with the mixture, which is then hollowed out in the center in the form of a trench, about twenty inches wide and deep enough to expose the ends of the carbon blocks in each head. The trench is filled with coarsely ground coke, the pieces being about the size of a pea, which forms a core twenty inches in diameter extending the whole length of the furnace and connecting the two sets of carbon blocks. More mixture is then piled on, being carried up in the form of an inverted "V" to a height of several feet above the walls. When the work of filling the furnaces is finished, the electrical connections are made at the ends. The circuit is completed through the carbon blocks in the heads and the core of coarsely ground coke.

Inasmuch as the electric current is utilized in these furnaces for heating purposes only, there being no electrolytic action, either a direct or alternating current may be used. But the conditions are peculiar in this respect, in that it is desired to maintain a constant flow of energy through a varying resistance. It is impracticable to attain this result

with a direct current without heavy waste, so that an alternating current is used. This is generated at the relatively high pressure of 2,200 volts for economy in transmission, and by means of a transformer placed near the furnaces, reduced to 140 volts. Connected with the transformer is an induction regulator, so constructed that the secondary voltage may be raised at will to 200 volts or lowered to 80 volts, or maintained at any voltage within this range. In the furnaces just described the current used is the equivalent in energy of 1,000 mechanical horse-power. It is carried between the transformer and the furnaces by heavy copper busbars having a cross-section of about eight square inches.

When the circuit is completed for the beginning of a run, the voltage is run up to the highest point. The carbon core being cold, its resistance is high, and for a short time the amperes are low; but as the core heats up, its resistance falls, full load is soon attained, and in order to prevent an overload, the voltage is slightly lowered. In the early part of the run, the temperature of the core rises quite rapidly, until a point is reached where the resistance becomes nearly constant, falling slowly, so that after this very little regulation is required.

After the circuit has been closed in the transformer room, no apparent change occurs in the furnace for about half an hour. Then a peculiar odor is perceived, due to escaping gases, and when a lighted match is held near the furnace walls, the gas ignites with a slight explosion. When the current has been on for three or four hours, the side walls and top of the furnace are completely enveloped in a lambent blue flame of carbon monoxide gas, formed by the combination of the carbon of the coke with the oxygen of the sand. During the run of a single furnace five and one-half tons of this gas are given off. At the end of four or five hours, the top of the furnace begins to subside gradually, and fissures form along the surface, from which pour out yellow vapors of sodium.

The chemical reactions which occur in the furnace are not perfectly understood. The silica is reduced, its oxygen uniting with part of the carbon in the coke, and the silicon set free to unite with carbon, apparently as a vapor which condenses in the crystalline form. These reactions take place at a temperature which it is impossible to obtain without an electric furnace. It has been estimated that the temperature obtained by the core is not less than 6500° F. What this means can be conceived only by recalling the temperatures attained in familiar cases. The temperature of the iron in the hottest zone of a foundry cupola does not exceed 3000° F., and near the tuyeres of a blast-furnace 3500° F. Platinum melts at 3200° F.

At the end of about 36 hours the current is cut off from the furnace and it is allowed to cool for a few hours. Then the side walls are taken down and the changed mixture raked off the top of the furnace, until the outer crust of amorphous carborundum is reached.

The crust is cut through with large steel bars, and can then be easily removed from the inner crust of amorphous carborundum. The inner crust is next removed with a spade and the crystalline carborundum exposed.

A cross-section of a carborundum furnace presents an interesting and beautiful appearance. In the center is the core, which on examination is found to be very different in some of its physical characteristics from the coke of which it was originally composed. It no longer possesses a bright metallic appearance. Many of the kernels are quite soft and can be squeezed between the fingers, leaving on them a mark like black lead. In fact, the high temperature to which the core has been raised has driven off all impurities from the coke, leaving nothing but pure carbon, either in the amorphous or graphitic form. From the core radiate beautifully colored carborundum crystals to a distance of ten or twelve inches. A single furnace yields about 7,000 pounds of crystalline carborundum. Most of these crystals are not remarkable as regards their size, but in places, where hollows have formed, large hexagonal crystals are found, sometimes measuring one-half inch on a side. At the distance of ten or twelve inches from the core, the crystals suddenly cease, and instead is found a thin layer of light green color, which is the inner crust of amorphous carborundum. Beyond this is the outer crust of amorphous carborundum, and this also ends in unchanged mixture. Other curious substances are sometimes produced in the furnaces; for example, silica, which has the appearance of spun glass. But perhaps the most interesting substance that is sometimes found is a curious layer next the core, of what Mr. Acheson aptly terms the "carbon skeleton of carborundum." On opening a furnace and cutting down to the core, a layer is found that appears at first sight to consist of very dull black carborundum crystals. On closer examination, however, it is found that, though this material has the exact form of the carborundum crystals, it is nothing but pure carbon in the graphitic form. This phenomenon is interesting for two reasons. It points out the probable explanation of the non-occurrence of carbide of silicon in nature, for this artificial graphite has been formed by decomposition of carborundum, the carbon being deposited in the graphitic form, showing that the temperature at which carborundum decomposes is very little higher than that necessary for its formation. Apparently the heat conditions in the earth's crust have never been exactly right for the making of carborundum. In the second place, it is the basis of another new industry—the manufacture of graphite artificially from coal. This has a future of great promise.

The carborundum crystals when taken from the furnace are of various shapes, some like needles, but most of them flat plates, with almost perfect hexagonal outlines. The coloring is usually black, but films are formed on their surface which show iridescent colors like those on a piece of tempered steel, of a brilliant lustre.

The masses of crystals are crushed under heavy rolls in a grinding pan, and the grains thus formed washed to remove impurities, dried and sifted into the various sizes required. In this form carborundum is sold like emery, for grinding and polishing, or it is put on paper and cloth, or made into wheels. The latter part of the business absorbs most of the carborundum used for abrasive purposes. The grains are mixed with a binding material consisting of certain fine clays, formed under heavy pressure in iron molds, and fired for some days in a pottery kiln. It thus results that a carborundum wheel is essentially a disc of fine porcelain in which is imbedded a quantity of carborundum in the form of grains. After firing, the wheels are dressed to size and shape, tested and inspected and then packed for shipment. The composition of the wheels is varied both in the size of the carborundum grains used and in the proportions of the binding materials. In these ways it is possible to produce wheels for every kind of work, from the coarse hard wheels for snagging castings to the fine wheels used by glass workers, and the soft wheels used on tempered tools.

The properties which render carborundum so valuable in all these forms of abrasives have been touched upon, but it will be interesting to recall them here.

Carborundum is apparently infusible; for, after a certain temperature has been reached, decomposition commences, without fusion, and the crystals are broken up into carbon and silicon. It is quite insoluble in water or any acid. Its hardness lies somewhere between nine and ten degrees, probably very close to ten degrees, which is the hardness of the diamond. An attempt was made to obtain some idea of the relative hardness of diamond, corundum and carborundum by the following experiment:

A series of lines were scratched on a small plate of glass with each of the three materials, and the scratches examined with a microscope. The appearance of the lines made by the diamond and the carborundum was indistinguishable, but that made with the piece of corundum was quite different, being rough, and not presenting the clean-cut outlines of the other scratches. This seems to show that carborundum is much nearer diamond than corundum in hardness, although it is not as tough. The specific gravity of carborundum is 3.123, which is less than that of emery, one and one-fourth pounds of the latter being equal in volume to one pound of the former. This is important for two reasons:

First. It makes the relative cost of carborundum less than it appears at first sight; and

Second. A carborundum wheel is considerable lighter than an emery wheel of the same dimensions, which, of course, is a distinct advantage.

As was mentioned before, the use of carbide of silicon as a chemical reagent was not originally contemplated. But when it was observed that it dissolved readily in molten iron, immediate steps were

taken to bring it to the attention of metallurgists. Its use in the manufacture of steel was first proposed in 1893, but its high cost of manufacture prevented any extensive experiment being made towards its introduction.

Early in 1895, with the prospects of great cheapening in the cost of production, John Darby began experiments in England which proved very successful. He was followed later in the year by F. Luermann, the well-known German metallurgist, and by the late Captain A. E. Hunt, who made it the subject of a United States patent.

During the past three years it has found wide and general application. At the present time it is being used in increasingly large quantities by several of the leading manufacturers of steel and iron castings, and a brief review of its special advantages and range of application is of interest to the metallurgist.

Carbide of silicon contains theoretically one atom each of silicon and carbon, making the proportions by weight, silicon 70 per cent., carbon 30 per cent. The commercial article, however, contains certain impurities, the average analysis being as follows:

Silicon	62.0
Carbon	35.0
Iron	1.5
Aluminum	1.5
Total	100.0

It also some times contains traces of calcium and magnesium. The iron and aluminum are not present in the metallic form, but like the silicon in combination with carbon as carbides. Of the total 35 per cent. carbon about 28 per cent. is in combination and 7 per cent. in the form of free carbon.

Although formed at a temperature of not less than 6500° F. and insoluble in any acids, it dissolves readily in iron at the temperature of the blast furnace or open hearth, and its high percentage of silicon early suggested it to metallurgists as a source of this element for the prevention of blow-holes and the production of sound castings.

The cause of the quieting action of silicon on violently foaming or boiling steel is two-fold, and while authorities may differ as to the relative importance of each action in the final result of a sound casting, there is general agreement that both actions occur.

The first is its action as a reducing or deoxidizing agent. Such blow-holes as are caused by carbon monoxide and carbon dioxide (and with these the open hearth process has principally to contend) are the result of a reaction between carbon and oxygen, the latter being either uncombined and in solution, or combined with the iron as an oxide (probably the protoxide, Fe O). On adding silicon either in the form of ferro-silicon, silico-ferromanganese or carbide of silicon the silicon displaces the carbon preferentially in the above reaction and a solid

body (SiO_2) is formed instead of gas. This readily unites with the ferrous and manganous oxides, forming a slag which rises and floats on the molten steel. This action, however, deals only with that portion of the silicon which is consumed and does not appear in the final analysis.

The second action depends for its accomplishment on that portion of the silicon which combines with or dissolves in the steel, and results from its well-known property of enormously raising the solvent power of steel for its occluded or contained gases. These may be carbon monoxide, carbon dioxide, hydrogen, oxygen, or nitrogen, though the three latter are of major importance in the Bessemer process.

The above results are obtained when silicon is added either in the form of ferro-silicon, silico-ferromanganese, or carbide of silicon, but in the latter case, however, with the addition of valuable and unique effects, best understood after relating its practical manipulation in the open hearth process.

It differs radically, in that it is a ladle addition instead of a furnace addition. The bath before tapping has been brought down, we will say, to a silicon content of .02 per cent. and carbon .10 per cent. The proper quantity of carbide of silicon in the form of powder and not previously heated, is dumped into the empty ladle, and the contents of the furnace tapped upon it. During this operation considerable reaction and commotion seems to occur, which, however, ceases about as soon as the ladle is filled, and the steel is ready to be drawn into the molds at once.

Here let us first note its advantage over ferro-silicon, as a means of raising the solvent power of the metal for its occluded gases. The mere presence of silicon in any proportion does not assure that the metal will be quiet in the ladle and solid in the mold, but rather the fact that it has been added just previous to casting. Increasing silicon raises the saturation point but it does not make supersaturation impossible by any later operation tending to introduce or liberate more gas. Even ferro-silicon containing 15 per cent. silicon may be porous after casting. A steel may be high in silicon and still be supercharged with gases and evolve them copiously on teeming, but a further addition raises its capacity for holding its gases and gives a tranquil metal. This being true, and in order that the final content of silicon may not be excessive, the addition of the same should be as late in the operation as possible, after all opportunity for reaction is past. With ferro-silicon the agitation of the metal and the entrainment of air due to tapping into the ladle might cause reaction and release of gases which the silicon previously added to the furnace, would not control. Carbide of silicon being a final ladle addition, precludes the possibility of any subsequent supersaturation of the metal from the generation or absorption of more gas.

The most valuable property of carbide of silicon, however, is its power of enormously raising the temperature and consequently the fluidity of the metal in the ladle. When disassociation of the carbide takes place in the ladel, a remarkable rise in the temperature is noted which is most easily accounted for on the supposition that carbide of silicon is an endothermic compound. The heat available from the combustion of silicon to silica is greater than from that of any of the common metals to the oxides, but this reaction occurs when ferro-silicon is used without so great a rise in temperature.

It will be noted in the analysis of the carbide of silicon given above, that it contains no phosphorus or sulphur. This is a matter of prime importance in many processes where the percentages of these elements are already at the maximum allowable limit and it is necessary to have the recarbonizing material free from these impurities.

The action of silicon in cast iron has been the subject of exhaustive study and investigation. Opinion is not wholly unanimous among authorities as to what extent it is the governing factor in determining the final quality of a casting; but it is well established that an increase of silicon will change combined carbon into the graphitic form, and thus give an increased softness very desirable in machine work. This action is probably most pronounced with the higher temperatures of the blast-furnace, and does not always occur in marked degree at the lower temperatures at which the cupola is operated. Silicon, then, is a softener and lessener of shrinkage only by reason of its influence on carbon. These two elements together are the governing factors and their occurrence in carbide of silicon in such large proportions, constituting as they do the entire product, make it an ideal material for supplying any deficiencies which may exist in the original iron.

One of the greatest difficulties with which the founder who uses any scrap must contend is dirty castings. The cause of this is most often traced to the iron oxides which may exist in the scrap in the form of rust or burnt iron, or may be formed from prolonged heating in the cupola. Silicon is a very active deoxidizing and reducing agent, and when used with iron of the above character it has the power of reducing a portion of these oxides to metallic iron and silica. At the same time, it unites with a certain proportion to form a fluid slag of iron silicates, preventing their appearance in the casting in the form of dissolved iron oxide, dirty and spongy metal.

Carbide of silicon has been found to be specially adapted for this purpose, making available iron carrying a large burden of dirty or burnt scrap. Many foundries are so situated as to transportation facilities that the use of scrap drawn from neighboring sources in place of pig transported from great distances becomes a matter of great economy, if not imperative necessity. As a fluxing material and softener for this class of foundries, carbide of silicon is most valuable. It has been found possible to melt a charge composed entirely of burnt or

small, rusty scrap, and by the judicious use of the carbide, obtain a clear flowing metal and a sharp solid casting. Without the carbide, there appeared to be more slag and dirt than iron, and it was wholly impossible to handle it.

In this case the carbide acts mainly as a reducing and fluxing agent. The metallic iron produced by the reduction of the oxides resulted in a direct gain, and was evidenced by the small amount of slag, and the fluxing action was very marked from the fluidity of the slag and the manner in which it remained free from the metal. In practice it is found that an amount of the carbide as low as one per cent. of the weight of the iron in the charge will have a marked influence on the quality of the castings and the behavior of the metal. This follows from its high silicon content, a very important advantage in convenience of handling and many other ways, when we consider that ferrosilicon carries only 10 to 14 per cent. silicon and Scotch iron as low as 6 to 8 per cent.

The method of handling carbide of silicon most successfully employed in cupola practice is to charge the carbide of silicon in lump or brick form along with the pig and coke, placing the proper amount on top of each coke charge, so that as the iron melts it will come in contact with and flow over the carbide, completely absorbing the same. It has a marked effect on the fusibility of iron and fluidity of the metal in the ladle, following in this regard the well known action of all the high silicon irons, tending to make them take delicate molds well and produce clean, sharp castings.

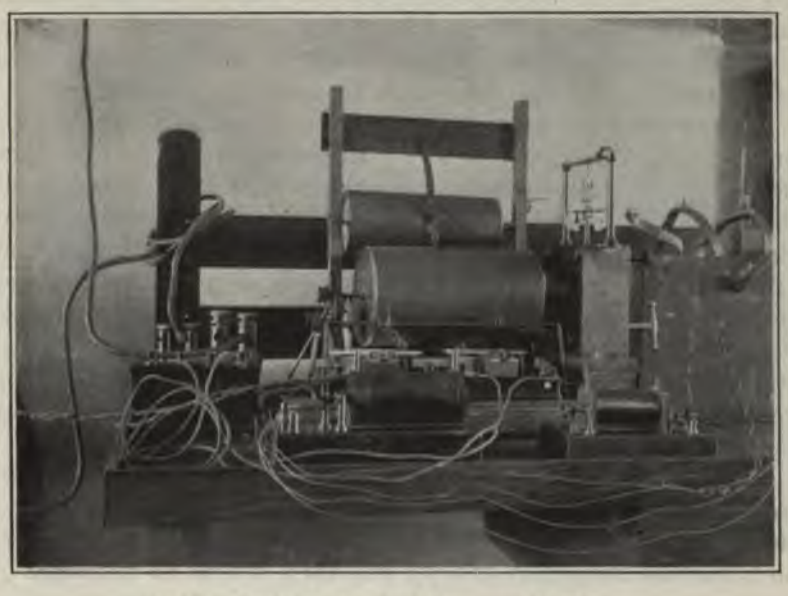
In the preparation of this article the writer is indebted to Messrs. F. J. Tone and F. A. J. Fitz Gerald, both of whom have made valuable contributions to the literature of the subject.

VOLTAGE AND CURRENT RECORDER.

FRANK W. SPRINGER.

The difficulty experienced in obtaining accurate readings of current and voltage taken by railway motors, electric elevators and the like induced the writer to attempt the construction of a device which would record the instantaneous values of current or pressure or both.

After considerable experimenting, the apparatus described below was constructed. It has proven successful for the purpose for which



CUT NO. 1. VOLTAGE AND CURRENT RECORDER.

it was designed, and as it is a combination of instruments in common use in electrical laboratories it is hoped that a description will be of interest.

Two cylinders, each five and one-half inches long, are mounted on the drum of an ordinary chronograph and are insulated from the drum by rubber rings of a uniform thickness of one-fourth inch. The adjoining ends of the two cylinders are separated from each other by a space of three-eighths of an inch. It is sometimes convenient, however, to bring the ends of the cylinders together, making one cylinder, when current, or voltage, alone is recorded.

The covers of a Weston direct current, dead-beat voltmeter and a similar type separate shunt ammeter were taken off and the ends of the

pointers of the instruments fitted with light aluminum spark-points short enough so that the covers might be replaced without interfering with the free movement of the pointers. The two instruments were then placed under the two cylinders respectively in such positions that when the pointers stood at one-fourth and three-fourths of the full scale reading, the spark points would be directly under the axis of the cylinders and about one-sixteenth of an inch from the black paper with which the cylinders are covered. The distance between the points and the paper is a maximum at zero, half scale and full scale readings. It is very desirable to have the gaps between the spark points of the instruments and the cylinders as small as possible and the same length for all readings. For this reason a drum of large diameter gives best results. On a rod at the side of the cylinders are placed two insulated spark points, one for each cylinder, and set within one-thirty-second of an inch of the paper.

Two induction coils, each capable of giving a continuous stream of sparks across a gap of one-fourth inch, are connected as follows:

One of the secondary terminals of one of the induction coils is connected to that binding post of the ammeter which is in immediate connection with the pointer of the instrument, and the other is attached to the spark point on the rod at the side of the cylinder, so that each spark makes two holes in the paper, one opposite the spark point of the instrument pointer which records the reading of the ammeter and the other opposite the fixed point. Two lines of holes are thus made in the paper; one more or less irregular corresponds to the movements of the instrument pointer, and the other being straight is used for a base line. The number of holes made by the sparks is adjusted for about 100 per second.

The second induction coil is similarly connected to the voltmeter. Care should be taken, when both instruments are used, that the ammeter is cut in on that side of the line with which the voltmeter pointer is in immediate connection in order that there will be no difference of potential between the pointers of the ammeter and voltmeter, thus avoiding any possibility of a short circuit between the two instruments.

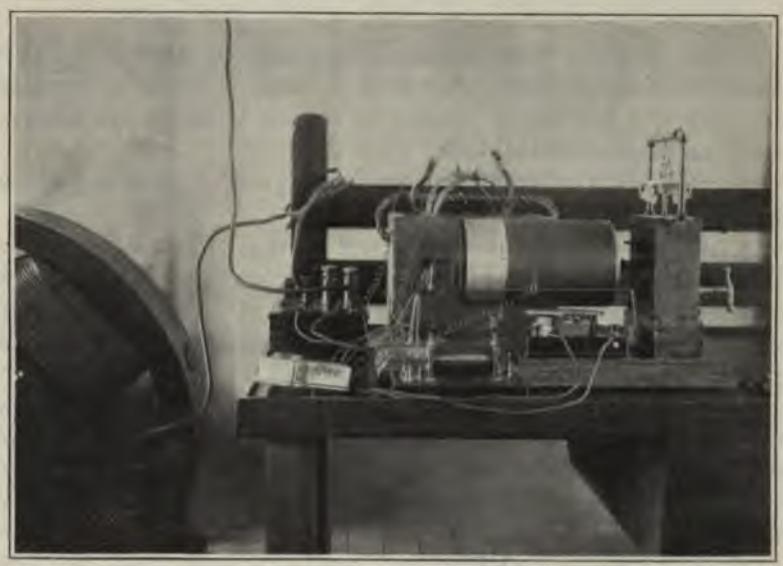
It was at first thought that the static attraction between the cylinders and instrument pointers would be great enough to cause the pointers to move toward those positions in which they are nearest the cylinders, thus making records too high or too low depending on the position of the pointers in reference to the one-fourth and three-fourth scale reading positions. This was found, however, to give no trouble when the stream of sparks was continuous.

Cut No. 1 shows the recorder complete. The upper roller carries a long strip of black paper which is passed around the main cylinders and wound on a second roller. The latter is operated by a train of gearing and clock spring just strong enough to balance the friction of the brake on the upper roller and to keep the paper tight on the

cylinders. The chronograph regulates the speed of the paper. Where there is considerable jar, as in work on cars, it is necessary to have some device to keep the paper from slipping. For this purpose a number of little brads one-sixty-fourth of an inch long were soldered at intervals around one of the cylinders. The small felt wheel, shown in the picture, forces the paper down on the brads, thus preventing the paper from slipping on the recording cylinders.

Cut No. 2 shows the apparatus as it is ordinarily used in recording the accelerating current of motors.

Curves *SZ* and *DN*, cut No. 3 were taken on a 500-volt, 40-horse power motor. Curve *DN* shows the building up of the current in the shunt field coil, starting at *D*, on throwing in the main motor switch,



CUT NO. 2. CURRENT RECORER.

and rising to *N* in about 4.2 seconds. The three ampere shunt was then exchanged for a 30 ampere ammeter shunt and the armature rheostat gradually turned on, the armature current starting at *Z* and rising to nearly 30 amperes, then falling off, as the motor speeded up, till the rheostat shoe was moved to the next step on the starting box. It will be noticed from the curve that the armature rheostat has six steps. The motor attained full speed at *S*, the time *ZS* being 15 seconds.

The vertical curves at the left and *HU* and *LK* were made by moving the instrument pointer over the full scale while the cylinder was standing still.

Curves 2, 3, 4, and 5 are taken from a test recently made on the Sprague electric elevators in the Hennepin County Court House, Minneapolis. Curves 2 and 3 show current and speed of an overbalanced

elevator of the drum type, Curve 2 being taken while the car was going up, and Curve 3 while going down. The time of starting is marked in all cases by the letter *Z*.

Curves 4 and 5 are from a Sprague electric elevator of the screw type. This elevator has an under balanced car which descends by gravity. Curve 4 was made while the car was going up and marks the starts and stops at four successive floors. In several cases the elevator failed to stop exactly at the floors. These short starts are marked *Zt*. In case of Curve 5, taken on a down trip, no current was used except where the car ran by the third floor a few inches and was brought back again.

ACCURACY OF THE RECORDER.

(1) Nothing need be said concerning the accuracy of Weston ammeters and voltmeters when used on steady currents and pressures.

(2) As mentioned already, the stream of sparks has little or no effect on the instrument pointers.

(3) Draughts of air can easily be guarded against by using a screen.

(4) As is well known, electric sparks do not always take the shortest path between two terminals, and this is especially true when one of the terminals is a nearly flat surface. This, however, introduces no difficulty as the curve traced simply becomes slightly wider and we have but to take the middle points to obtain the curve.

(5) The lag of the pointer behind the current (or voltage) while introducing no great error, makes it difficult in some cases, perhaps, to interpret the curves accurately.

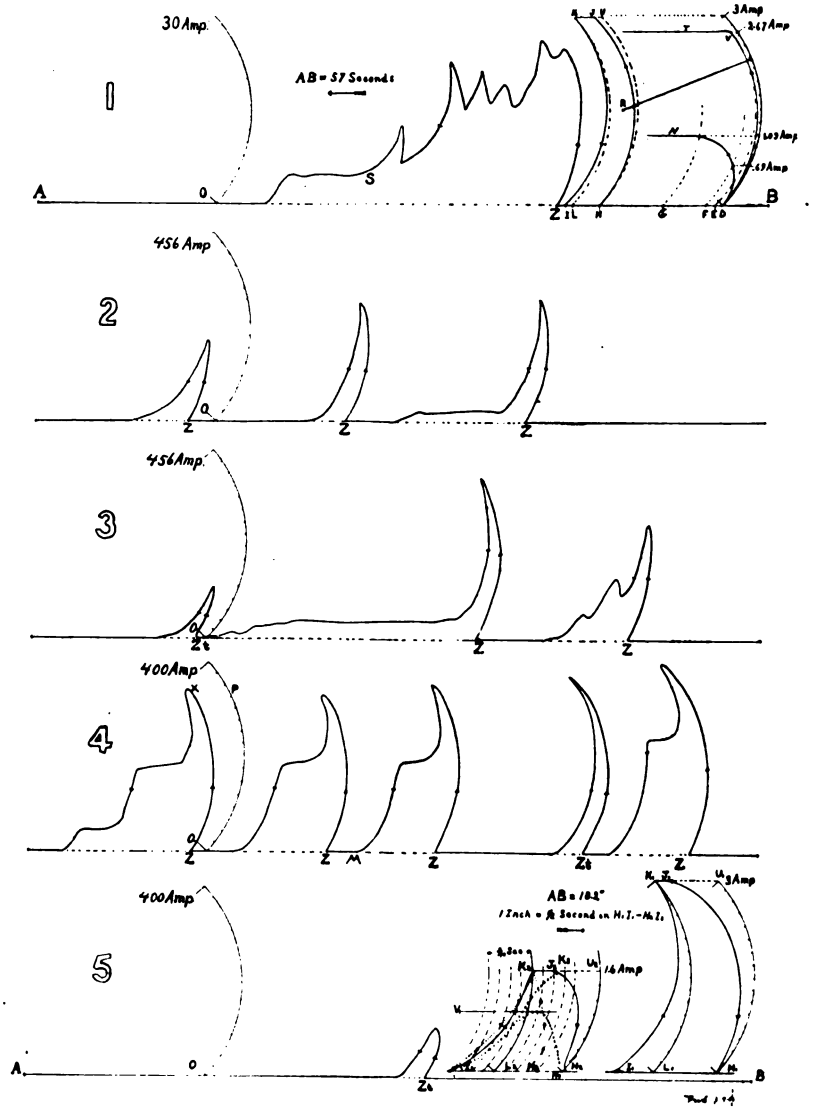
The first test of the lagging effect was made in connection with Curves 1. An incandescent lamp resistance was connected in series with the ammeter and the current turned on, first, while the cylinder was still and then while turning at the rate of one revolution in 57 seconds, the latter giving curve *DVT*. The "rounding" at *V* is largely due to the change in resistance as the lamp filaments became heated.

For Curve *HJKI*, a non-inductive resistance with zero temperature coefficient, was connected in series with the ammeter and current supplied from a storage battery. On throwing on the current it immediately rose to the maximum on *HV* and the pointer traced *HJ*, the lag being *JU*, which is equal to about 5-10 second. The current was left on *UK* seconds when the switch was thrown, the current falling to *L* and the pointer tracing *KI*. The lag is equal to *JU* so that the area *HJKI* traced by the instrument, is equal to *HUKL*. The error in the motor curves is thus very small.

Curves H_1, J_1, K_1, I_1 and H_2, J_2, K_2, I_2 were made under the same conditions as the above except that the cylinder was run faster, the speed being such that *AB* equals 9.1 seconds. The lag L_1, I_1, J_1, U_1

and L_2, I_2, J_2, U_2 is about 5-10 second. The lag appears to be the same under these conditions regardless of current strength.

This would indicate that, practically at least, any current suddenly thrown on the ammeter would have to continue 5-10 of a second to be



CUT NO. 3. CURVES TAKEN BY CURRENT RECORDER.

recorded. If then the current be turned off quickly it would require another period of 5-10 second for the pointer to come to zero. The base line record would show one second between the start and stop while in fact the current would only have continued 5-10 second.

If R be the retarding force causing the lag, Ka the acceleration resistance or force of the moving parts, Av^2 the air resistance, where v is the velocity of the pointer, Ev the damping effect of eddy currents in the instrument-coil frame, and F the friction, (F is small and may be neglected.)

$R=+Ka+Av^2+Ev$ for increasing velocities of the pointer,

$R=-Ka+Av^2+Ev$ for decreasing velocities of the pointer.

Further, if C be the current force and S the spring force at any instant,

C-S=R for increasing readings, and

S-C=R for decreasing readings.

In other words, the "lag force" is always equal to the difference between the current force and that of the spring, or, it is equal to the accelerating force tending to move the pointer.

On account of the inertia effect of the moving parts of the instrument the difference between C and S for the same velocity of the pointer may vary widely in different parts of a curve. This is due to the fact that in the first part of a curve the pointer is being accelerated and in the latter part the velocity of the pointer is decreasing and the inertia of the moving parts assists in moving the pointer against the retarding factors, Av^2 and Ev.

In regard to the lag being 5-10 second for all ranges of current, it may be added that it is probably somewhat less for small currents because the air resistance, Av^2, increases with the square of the velocity of the pointer. The difference, however, cannot be noticed on the curves.

The lag in case of a changing current, as for instance where the current is uniformly increased from zero to its maximum in a given time, will be at any instant 5-10 second less an amount depending on the inertia, Ka, of the pointer at that instant. For example—in Curves 5—I_2K_2 (dotted line) is the curve of a current uniformly increased from 0 to 1.6 amperes in 5-10 second. The curve traced by the pointer will be some curve as I_2K_3 (xxx) such that if the current after reaching 1.6 amperes be continued at this amount the traced curve I_2K_3 will lag so that K_2K_3 will be 5-10 second, less an amount depending on the inertia of the pointer at the instant the true curve reached 1.6 amperes. If, however, the current be uniformly increased to 1.6 amperes and immediately on reaching that amount be decreased at the same rate, making curve K_2H_3 (dotted), the traced curve will not reach the 1.6 ampere line at all. It will continue rising as long as the current, whether decreasing or increasing, is above that indicated by the pointer, and also will rise for a brief period after the current has fallen below the reading of the pointer, owing to the inertia of the moving parts. The traced curve will then be such a curve as I_2H_4 (xxx) with its maximum at some point as V_1, and meeting the base line at some point H_4 such that H_3H_4 is 5-10 second, less an amount depend-

ing on the inertia of the moving parts of the instrument at the instant current became zero.

The lag in *time* of a very slowly changing current, as already mentioned, is something less than 5-10 second, but the lag in *position* of the pointer compared to the true reading may be so small that the traced curve will practically coincide with the true curve at every instant. Suppose, for example, that we have a current very slowly increasing from zero and consider the effects of the three factors which have to do with the retarding force. The acceleration of the moving parts will be taking place over a comparatively long time and hence the accelerating force, Ka, will be small. Inasmuch as the change in current is small in a given time, the velocity, v, of the pointer will be small and hence the force, Ev, due to eddy currents in the instrument coil frame and the resistance, Av^2 due to air friction will be small. Then the aggregate retarding force tending to resist motion or change in motion of the pointer will be small. As this retarding force, R, is always equal to the difference between the spring force, S, and the current force, C, C and S will be nearly equal and the traced curve and the true curve will nearly coincide at every instant.

TEST OF 500 H. P. ALLIS ENGINE.

J. J. FLATHER.

During the past winter the Senior class in Mechanical Engineering was privileged to make a commercial test of a large engine located in one of the flouring mills in Minneapolis; and as the result showed such exceptional economy it has been thought best to give a short resumé of the test.

The engine was an 18 and 38 by 42-inch horizontal cross compound "1890" frame, made by the E. P. Allis Co., of Milwaukee. The economy was guaranteed as follows:

"We guarantee that this engine when running at 90 revolutions per minute, with 130 to 140 pounds steam pressure, with a steady load of about 450 horse-power, will require not over 13½ pounds of dry steam per horse-power per hour delivered to the engine cylinders, with a vacuum of 26 inches in exhaust pipe close to the engine."

Before beginning the test the engine was run for several hours under a load of about 525 horse power, in order to obtain a perfectly normal condition for the trial. During this period, indicator diagrams were taken at frequent intervals, and the load gradually diminished to that under which the test was to be made.

Four Thompson indicators were used in obtaining the indicator diagrams; 80 and 16-pound springs being used in the high and low pressure cylinders respectively. In order to obtain an accurate determination of the pressure below that of the atmosphere in the low pressure cylinder, occasional cards were taken with a special vacuum spring, from the results of which, corrections were made on the indicator diagrams. As an additional check, one of the 16-pound springs was calibrated when hot by using an air pump and mercury column, and the results were practically identical with those obtained with the vacuum spring.

A steam gauge was placed in the steam pipe just above the throttle and a throttling calorimeter was used to determine the quality of the steam. The vacuum was determined by means of a mercury column attached to the exhaust pipe just below the low pressure cylinders. The receiver between the low and high pressure cylinders was steam jacketed, and during the test the jacket water was trapped out and weighed. A Wheeler condenser was used with the engine, which permitted all of the condensed steam to be run into tanks and the water weighed at regular intervals.

Observations and indicator diagrams were taken every ten minutes throughout the trial.

The principal dimensions of the engine were as follows:

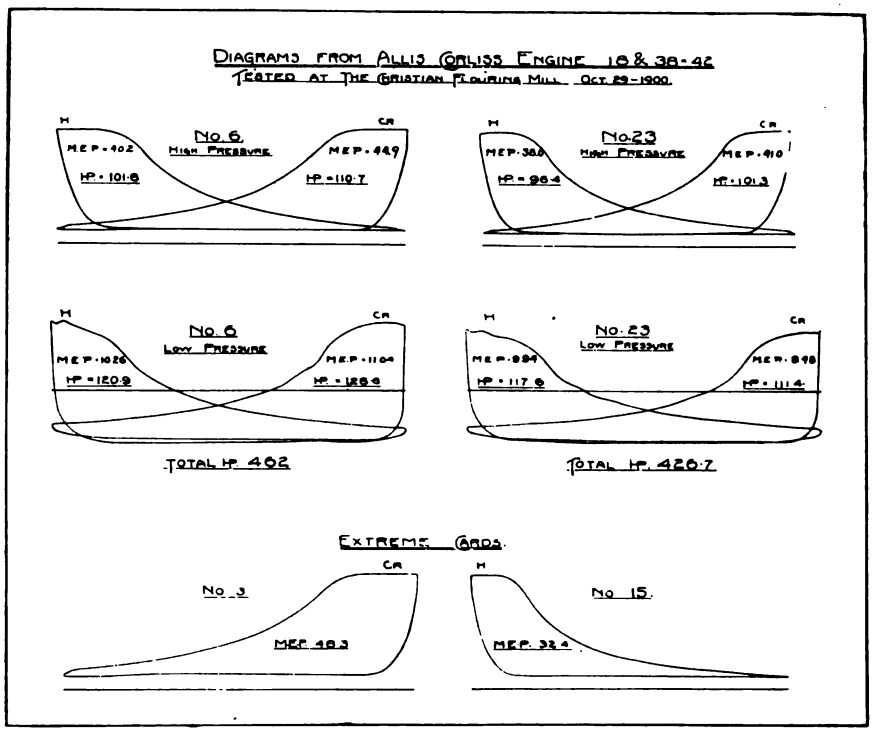
Diameter of high pressure cylinder	18	inches
Diameter of low pressure cylinder	38	inches
Length of stroke	42	inches
Diameter of high pressure piston rod	2-15/16	inches
Diameter of low pressure piston rod	3- 5/ 8	inches

SUMMARY OF OBSERVATIONS.

Duration of test 12:05 to 5:35	5.5	hours
Average M. e. p. in high pressure cylinder, head end	39.10	lbs.

Average M. e. p. in high pressure cylinder, crank end	44.85	lbs.
Average M. e. p. in high pressure cylinder	42.14	lbs.
Average M. e. p. in low pressure cylinder, head end	10.40	lbs.
Average M. e. p. in low pressure cylinder, crank end	10.569	lbs.
Average M. e. p. in low pressure cylinder	10.487	lbs.
Correction for error in low pressure indicator spring	0.46	lbs.
Average M. e. p. in low pressure cylinder	10.947	lbs.
Total number of revolutions	30,959	
Average number of revolutions per minute	93.81	
Total lbs. of steam condensed,—from cylinders	31,787	
Total lbs. of steam condensed from jacket	1,458	
Total lbs. of steam condensed during test	33,245	

Steam condensed per hour	6,044
Average gauge pressure of steam at throttle	138.23
*Average gauge pressure at boiler (corrected)	143.36
Average pressure of steam in receiver	18.97
Average inches vacuum in exhaust pipe at cylinder	25.6
Steam condensed in receiver jacket per horse power hour	0.58
Average height of manometer in calorimeter	1.31
Average temperature in calorimeter	243.7
Average barometer reading	29.646
Per cent of moisture in steam	3.5



Pounds dry steam per hour	5,833
Average horse power in high pressure cylinder	210.53
Average horse power in low pressure cylinder	245.92
Total horse power	456.45
Pounds dry steam per horse power hour	12.77

From the above it will be seen that the engine has far exceeded the contract requirements. An examination of some of the indicator diagrams, copies of which accompany this report, show that the engine was not working at its most economical load. With heavier loads, however,

* The gauges of the boiler were tested after the trial and found to be about 4.5 pounds fast.

a preliminary test showed that it was impossible to maintain a better vacuum than 23 or 24 inches. With a larger condenser, the engine would undoubtedly show a greater economy with increased load.

It is a pleasure to note that the builders of the engine were represented by Mr. J. H. Lewis, who maintained a spirit of perfect fairness throughout the entire test.

The corps of observers was in direct charge of Prof. H. E. Smith, of the University of Minnesota, who was ably assisted by the following gentlemen:

Mr. C. C. Jett, instructor in mechanical engineering—Indicators.

Mr. W. B. Newhall, assistant in engineering laboratory—Indicators.

Mr. L. E. Daniel, graduate student—General Log.

Mr. E. Wilson, senior student—Steam Consumption.

Mr. J. C. Quense, senior student—Steam Consumption.

Mr. P. Robertson, senior student—Water Meter and Steam jacket.

SOME EXPERIENCES WITH HIGH TENSION.

A. C. PRATT, E. E., '99.

Remarks are frequently heard expressing surprise at the remarkably rapid growth of the high tension business. A little thought, however, will lead to the understanding that the growth is really nothing more than the normal growth of an industry which has for years been setting its roots and getting ready. It really requires less engineering daring to install a 50,000-volt transmission plant to-day than it did to attempt a 10,000-volt plant a few years ago.

However, while in most respects we may anticipate results very closely, yet there are many details where things of much interest are constantly developing. The general public also are being educated to some sort of an appreciation of what high tension transmission means.

This latter matter might hardly be classed among the engineering features, but experience shows that the public offers no mean obstacle to many proposed installations. Ranch men object to granting right of way for a line for fear of damage to their chickens or their cattle; their children or their crops. Others fear that the menace of that dangerous current will cause real estate to slump. Then a telephone manager who is sure his business will be at an end if that line comes near him finally decides you may cross his line if you will go off about a mile; get a good square start and cross his line at 90 degrees, no minutes, no seconds. Then there is a large body of aldermen whose pockets must be lined before they can believe that the interests of their constituents will not be placed in jeopardy by that new line. But when all these and scores of other difficulties have been met a high voltage plant runs as smoothly as any other of as good general design.

My observations on specific troubles and peculiarities incident to this class of work, must be chiefly regarding the installation where most of the observations were made—the plant of the Missouri River Power Company at Canyon Ferry, Mont. The company is at present installing six generators of 1,000 horsepower each to transmit power about 65 miles to Butte and perhaps to Anaconda. But for some time past have been operating merely four generators of 650 k. w. each, supplying four 3-phase lines at 11,500 volts through transformers raising from 550 v., 2-phase, to 11,500 v., 3-phase.

The load is chiefly induction motors of from 500 to 175 and smaller horsepower ratings; but includes the street car system and all the lighting of Helena.

In a plant transmitting at such a moderate voltage, the actual high tension apparatus, including the line, requires the least attention:

a thorough inspection of line and apparatus once a month seems sufficient and the main troubles are:

First—Insulators broken by boys or hunters. A broken insulator causes no disturbance even though two adjacent wires touch the crossarm and the trouble is confined to replacing it. This may be done in fair weather by grounding the wire to the pole below the feet of the lineman and doing the work with the line alive. If possible, however, the line should be killed.

Second—Hay wire or the like thrown on the wires by boys, mischievous or worse. The procedure is to burn it off as fast as it is thrown on if possible, and it is rather surprising that while such a sized short on a 500 v. circuit would be fused almost instantly, yet on the end of a 20-mile, 11,500-v. circuit, backed by 2,000 or 3,000 k. w. capacity in generators and transformers, it takes an appreciable length of time to burn off even a small baling wire. With 18 inches between wires the arc will not hold more than an instant. The breaking of the arc, however, is probably due to slowing of the water wheels and considerable resultant drop in voltage. In this, as in several other respects, a water driven plant is very different from a steam driven station. Water wheels rarely have much overload capacity and promptly slow down on a short. An arc will flash instantaneously ten feet high, with a loud report, and then break.

It may be remarked here that automatic circuit breakers are not in good graces in many plants. They let go just when they should hold on. Even an initial charging current on a 35-mile, 30,000-v. line has often thrown breakers set for heavy overload. A partial short following lightning discharge over several arresters at once will throw all the breakers at once when the short would promptly clear if there were no breakers.

Fuses are much more trustworthy while hand tripped or time element automatics give best satisfaction.

Third—Trouble due to lightning. Contrary to popular expectation, lightning promises less trouble, rather than more, with increase of voltage, nor will the trouble increase in proportion to length of line. If lightning occurs on one end of a 20-mile line it will rarely seek the arresters at the other end and it is to be expected that a storm near one end of a 75-mile line, equipped to carry 50,000 volts, will scarcely be noticed at the other end. In a country of mixed mountain and open range, nearly all trouble comes from the open country. The mountain protects the line in its vicinity.

Further, it seems that many strokes which would break through arresters adjusted for a normal 10,000 volts, will not break through arresters adjusted for a normal 50,000 v.

An important adjunct to a transmission plant is its private telephone line, which is usually strung on the same poles as the power

circuits. The telephone line is transposed every fourth pole; the power lines not at all. The telephone line and everything connected is very thoroughly insulated from the ground and the exchange is operated by baby knife switches. A Western volt-meter of about 10,000 ohms resistance will show from 500 to 650 volts between line and ground. Probably a static volt-meter would show much more, for careful test with a spark gap proves that, under ordinary conditions the line will spark to ground through over 1-32 of an inch and sometimes through a full 1-16 of an inch. During rain the pressure is lower.

If one or more power circuits are running at a slightly different frequency from the others a spark will jump at every "beat." Several schemes might be adopted to reduce this pressure but it is scarcely worth while as the service is always satisfactory as it is. Lightning protection consists of a regular Wirt 2,200-volt arrester to ground, and a very short gap between carbons, across the lines. This latter protects the bridging bells in case a discharge from one line tends to produce an unbalanced condition.

It is always noticeable that, although the telephone circuit is below the power circuits, its arresters are always the first to warn the operator of approaching lightning, sometimes sparking very frequently without any discharge whatever, being noticed through the high tension arresters. This corroborates the statement previously made that the higher the normal line pressure, the fewer the lightning discharges which may be expected to reach ground through the arresters.

Something of a departure from text book wisdom may be noted in the matter of transformer connections. We are told that for high tension the star connection offers very considerable advantages, especially a reduction of the pressure across terminals of any individual transformer and the grounding of the neutral to preserve minimum pressure between all lines and the ground.

With the delta connection there is the maximum line pressure across terminals of each transformer and a more or less uncertain pressure between wires and the ground. A dead ground on one wire, however, merely throws a little additional strain on the insulators of the other two. In star with the grounded neutral, it means a short.

Again, in order to take advantage of the smaller pressure in star connection, the insulation of star connected transformers is made weaker than for the same line pressure with delta connection. The result is less resistance to puncture by lightning jumping from winding to core, which often offers a fair path to ground. In some cases the cores and transformer cases may be intentionally grounded, in which case evidently the normal pressure between core and winding is the same as in delta except that the maximum stress is from one terminal of one transformer to another terminal in a second transformer, i. e., beween any two line terminals, through the cores which are made one by grounding.

Perhaps the strongest reason of all, to the mind of the manager who is after continuous service above all things, is the ease of cutting out a transformer from the delta connection. Switches or circuit breakers are provided on both primary and secondary terminals of each transformer and in case of transformer disability due to a hot cable connection, bad switch, short, puncture, ground or some other condition which may arise, these switches may be immediately opened without removing the load from the set of transformers. This feature may also be found convenient if it is desirable to work transformers at the point of maximum efficiency. Two or three transformers may then be worked at a time in each set, according to the load.

A transformer can be cut out of star only by an elaborate system of switches and one or more reserve transformers, and even then it is impossible when there is urgent need of haste, while in the case of the delta connection even a short in the transformer is possible to be cleared by either automatic breakers or breakers tripped by a button or other device handy to the attendant.

A summary of the conditions restricting the maximum possible voltage which may be used on a line may be found in various text books. In truth, almost any voltage may be carried with proper construction. The limit is found when we inquire if it would be commercially a success. An inspection of the curves from Bells' Electric Transmission, page 489, shows that the pressure is easily reached above which mere length of cross arm would set a limit to allowable voltage. If then, the voltage is to be further increased, it must be with separate poles for each wire and other special constructions not yet to be thought of. Moreover, let one attempt to arrange interior and outgoing wires for, say, 75,000 volts transmission, and he will find that all outdoors with a roof over it is about the room he wants. Evidently more copper and less money in special construction would be better than to attempt too high pressures.

One example from the many incidents peculiar to high tension work is the following: A few days ago we mounted three 50,000-volt switches on some 11,000-volt transformers, feeding a printing office power equipment. The mounting of the switches differed from the 50,000-volt mounting in that the marble base of each switch was bolted directly to a thoroughly seasoned wooden frame, instead of glass insulators, all live metal, however, clearing the wood by at least six inches. As soon as pressure was put on, the two outside switches discharged with a strong humming noise, a violet colored brush about one-eighth inch long all around each switch terminal.

If one touched the marble his arm would feel numb; if the bases of the two switches were connected with a wire there would be fire around the ends of each wire; if either outside switch was pulled, the middle switch, hitherto quiet, would immediately discharge like the

others. The discharge seemed independent of changes in load conditions on the line. Additions of inductive load, rotaries or lights did not affect it. After three days there was no discharge, only a blackened ring around each terminal. Evidently it is hard to say if this was mere leakage or charging current or higher harmonics or some other manifestation. So long as the service is unimpaired and profits are not cut down, the station man has other things to look after rather than studying the cause of such an obscure manifestation.

In closing, it may be well to emphasize the well known fact that good construction pays in long distance transmission as much and even more than elsewhere and that the same precautions as to careful inspection and repair are well repaid in final results.

MAIN BUILDING, UNIVERSITY OF MINNESOTA.

ART IN ENGINEERING DESIGN.

W. H. KIRCHNER.

The various branches of engineering exist to satisfy practical needs. Engineering in so far as it provides for these needs is a useful or mechanical art. But that is not all. Architecture is not simply the art of building, or even of building well.

Vitruvius lays down three qualities as indispensable in a fine building, namely: stability, utility and beauty. The last is the principal element when architecture is considered as a fine art.

It has been said that the original type of the architect, considered as an artist, is the savage who first arranged the skins and timbers of his tent or hut in one way because it pleased his eye, rather than in some other way which was as good for shelter.

Since the province of engineering is daily expanding, it is not a simple problem to select the rudimentary type of the engineer, either as an artist or artisan. But, in every branch of engineering it is possible to show that there is in addition to the practical industry an artistic industry.

The relation of engineering to architecture is much too complex to be stated in any single class distinction or resemblance. It is of interest to note that Vitruvius, who for centuries was the chief authority studied by architects, is classified by the biographers as a Roman architect and engineer. His celebrated work, *De Architectura,* contains much that is not now included in architecture. Book X. is on machinery, with a preface on law, thus indicating that in the reign of Augustus, the architect, the engineer, and the contractor were not separated as at present.

If we add to the three elements—stability, utility and beauty—a fourth, economy, we have the most, if not all, of the qualities that are indispensable in a fine machine or structure. The proportioning of parts to resist deformation—to obtain stability—can in most cases be calculated, and is of itself a science. When the forces cannot be accurately determined the designer depends upon the most approved practice covering similar conditions and upon experiment. This, in addition to skill, requires a study of previous productions of his art. The use is prescribed and to that end there must be one way that is the best, thus requiring skill and invention.

Material, labor, power, space, and time are some of the factors which enter when we consider economy. The selection of the material is by no means an easy task. A minimum amount of material

and the necessary cost of production and construction is often not as economical as more material involving less labor.

The design and arrangement of parts to obtain the best results include such problems as efficiency in production or consumption of power, wear and tear, quantity and quality of product, place and time in which it is done or to be done, involving in many cases a careful consideration of providing for contingencies which may arise from natural or artificial causes.

The solution of the many and varied problems arising requires a practical understanding of the elements of a number of occupations, trades, and professions. It is noticeable in criticisms or courses of study in engineering, that those who are qualified to treat the subject usually consider which are the more essential of several subjects, and do not state—like beginners—that certain studies are of no use.

It is not because the engineer is expected to be a first-class pattern-maker, machinist, and engine-driver, that he devotes time to the practice of these trades. Instruction in the machine shop is given the student not to acquire the skill and facility of the machinist, but to enable the student to become familiar with the construction and use of machinery. Because the work of the student does not in all cases compare favorably with that of the experienced workman is no valid reason that the time is unprofitably spent. Likewise, it can be shown that the time devoted to many other subjects—even if in some cases it is a very small amount—is not lost.

Since beauty is an indispensable element in good design, the engineer must acquire an understanding of the fundamental principles of art and decorative design.

If we attempt to define beauty we are confronted by a most formidable array of speculation and discussion. If, however, we attempt to state why the appearance of one structure pleases us and the contemplation of some other structure fails to afford us any pleasure, we are considering properties that are governed by laws which are capable of being demonstrated.

It is true that many engineers have designed beautiful structures, without having studied the principles of composition; nevertheless they possessed an appreciation of the qualities which give pleasure to the beholder. The artistic end was not obtained by any spontaneous act, but is the result of deliberation, involving imagination and knowledge.

Much can be done to aid in the development of the power of imagination, but that portion of the artist's work which is the result of his effort to attain perfection according to his individual ideal, is beyond the domain of analysis. Personality is not a matter of rule and precept.

The engineer designs under many limitations of material and method. These limitations are not a hindrance but if properly under-

stood are of great assistance in attaining the most truth and beauty.

"Design, in the highest acceptation of the term, and composition stand in the same relation to one another as poetry and versification. The former cannot be taught; the rules that regulate the latter can be taught."*

Composition in design includes the harmonious grouping of the several parts, the proportioning of parts, and the treatment of details; in accordance with the canons of good taste and the precepts of custom or tradition. This requires an appreciation of such qualities as: aspect of strength, fitness, unity, relations of lines and intervals, proportions of masses, disposition of light and dark, and contrast of color. The following are the fundamental principles or laws of composition: principally, repetition, variety, contrast, curvature, and harmony. As applications or conditions of the above laws we have: simplicity, symmetry, radiation, alternation, interchange, counterchange, continuity and consistency.

Beauty cannot be obtained by a formal application of any of the above rules, nor is it likely that its creation will precede its appreciation. A study of the principles of composition, will, however, lead to a fuller appreciation of beauty, and often assist in its expression.

* F. G. Jackson, Decorative Design.

GENERAL VIEW.—*By courtesy of Electrical Review.*

THE POWER DEVELOPMENT AND TRANSMISSION OF THE ST. CROIX POWER COMPANY.

By John Lyell Harper.

The constantly increasing tendency of power consumers in large cities, to reach out after cheap sources of power, is rapidly causing the development of all the available waterpowers in the neighborhood of these centers of demand; and the transmission of their energy by means of high potential electric currents to convenient points of distribution. Distances of transmission have become longer, and the practical limits of potential higher, until in the completion, and successful operation of the St. Croix Power Company's 27-mile, 25000-volt transmission of power for the lighting of St. Paul, both of these factors must be considered well within the limits of modern practice.

It is, however, unique, in that part of the transmission line is underground. Being, I think at present, the only instance where as high as 25000 volts are transmitted successfully through underground cables, for commercial purposes, therefore a further description of the plant might prove of interest.

The plant is located on Apple River in the state of Wisconsin, at a point where the river has a natural fall of thirty feet. A short distance above this, a dam was built which raises the water forty-seven feet higher. From the dam the water is carried down river on top of the bank in a wooden flume, buried in earth, to a point below the falls where a head of eighty-two feet is obtainable.

Apple river drains a section of northwest Wisconsin which abounds in lakes, many of them being quite large, which, with the innumerable springs along its banks, give the river a remarkably constant year-round flow. The minimum flow was estimated as capable, with the head obtainable, of developing 2,000 horse-power throughout the twenty-four hours. And with the large storage capacity of the dam, 5000 horsepower can be drawn from the reservoir for a few hours without materially lowering the head. Thus allowing the plant to carry the peak of its lighting load.

The dam is of the arched type, its arc having a radius of 450 feet. It is 350 feet long, and its spillway is 110 feet in length, with abutments on each side rising four feet above it. The dam is built with a masonry core of brown sandstone, quarried from the banks of the river near by. This core rests on a concrete foundation, and is encased in concrete walls twenty-four inches thick on the down river side and eighteen inches on the up river side. All concrete was made

of the best Portland cement. Near the bottom, on the north side, there are two steel pipes, each five feet in diameter, built into the concrete, through which the water can be drained from the dam.

At the south end of the dam are the trash racks, through which the water passes to the head gates and into the flume; which is constructed of an Oregon fir frame work, lined with four-inch pine planks, its inside dimensions being fourteen feet six inches by fifteen feet six inches.

With a velocity not exceeding three feet per second, it will convey 670 cubic feet of water per second.

The flume is about 1500 feet long and ends in a steel forebay, on the top of the cliff above the power house.

THE DAM. *By courtesy of Electrical Review.*

Unusual precaution was necessary in the construction of this forebay for the reason that it is located on the top of a fine sand bank. It was therefore placed 100 feet back from the edge of the bank. It consists of heavy masonry walls, inside of which is placed a steel box twenty-four by twenty-four by seventeen feet deep, designed to connect the wooden flume with the steel penstock which carries the water down the bank to the power house.

Just in front of the forebay, at right angles to the flume, and extending ten feet below the bottom of the flume, is a concrete seepage wall, forty-two feet long and three feet thick, which prevents any leakage from the flume from injuring, or endangering the edge of the bank.

In order to prevent the top of the flume from being put under pressure, and the forebay from being overflowed in case of unusually

high water, a spillway, which is equipped with gates and a wooden runway for carrying the water back to the river, was constructed in the side of the flume near the upper end.

The penstock connecting the forebay with the power house is a steel pipe, 12 feet in diameter and 200 feet long.

The power station is a fire-proof structure of brick, with an iron roof, 140 feet by 50 feet.

The wheel room is separated from the dynamo room by a wall running lengthwise of the building. It contains four sets of two thirty-six-inch horizontal "Victor" turbines, each set receiving water through a 56-inch cutoff valve from the main feeder pipe. A fifth pipe from the feeder supplies two small turbines which operate the two exciters.

12-FOOT STEEL PENSTOCK.
By courtesy of Electrical Review.

Each set of turbines is directly connected to a 750 K. W. General Electric Alternator, operating at 300 r. p. m. The exciters have a speed of 825 r. p. m. and generate current at 125 volts, either exciter being capable of exciting all four alternators.

The water wheels are governed by the latest type of the Geisler electric governors, of which a more detailed description might be of interest. These machines at once impress the observer with their compactness, and the ingenious placing of a large amount of machinery in a small space.

The governing of water wheels is at once a difficult and necessarily an approximate undertaking. A governor's action depends upon the change of speed of the wheels, which it should keep constant.

There must, therefore, be some change of speed before the governor can act to correct it. The efficiency of the governor then depends upon its sensitiveness to these changes. The revolving balls are now almost universally used to receive these changes and transmit them to the governor. Their action, however, to be sensitive must necessarily be weak. Therefore, there is required the introduction of some working medium as a connection for transmitting the delicate action of the balls to some source of power sufficient to operate the heavy gates.

In the choice of this connecting medium lies the principal difference in governors, and from it they take their principal characteristics.

Some types make use of a fluid under pressure of oil, for instance, as in the "Lombard," or a pure mechanical connection as in the "Replogle" and the "Faesch-Piccard." The designers of the Geisler governor consider that in the use of the electric current they have secured the most sensitive and flexible medium possible. These governors take their controlling current from the station exciters, at 125 volts.

One of the supply terminals is connected to a contact bar which is connected to the stem operated by the balls, and is adjusted so as to be horizontal for the desired speed of the wheels. Just below the contact points on the ends of the bar are mercury cups. While the bar is maintained horizontal, no contact is made; but when the speed changes and the bar is tipped it makes contact at one end with the mercury. These cups are each connected to a magnet operating a common armature, which in turn operates a friction plate, connecting the governor with its source of power, which in this case is taken direct from the wheel shaft. The action of the governor causes an opening or closing of the supply dependent on which cup and magnet the contact was made through. Between the contact cup and the magnets are inserted cut-off cups, which automatically open the circuit and stop the action of the governor before the gates reach their limits in either direction. When a contact is made and the governor acts, the contact cup is quickly lowered out of range of the points, then is raised again to its former position by a much slower motion. During the time of this travel of the cup, the contact bar has, by means of a mechanical device independent of the action of the balls, but dependent upon extent of the action of the governor, been returned to a horizontal position. Thus it is again ready to answer to the requirements of the speed, with equal promptness in either direction. The connection from the friction plates to the gates is made through compensating, and reducing gears. The whole gate opening is eight inches, and the governor is designed to make this in one complete stroke, in nine seconds. The power required is practically of 3200 pounds per wheel.

The four 750 K. W. generators are of the revolving armature type, giving 60 cycles at 300 r. p. m. The armatures are connected and give 800 volts between rings. They are connected to the switch-

board by three lead-covered cables, laid in a covered trench in the floor.

The switchboard is constructed across the building, between the generators and the transformers. It consists of eight panels of blue Vermont marble, supported on an iron frame.

In switchboard design and construction there are two main points of consideration, namely, the simplicity and flexibility of arrangement. In these two particulars, the designers of this board consider that they have practically an ideal arrangement. The failure of no one piece of apparatus, or machine can completely cripple the system.

The exciter panel contains a voltmeter, two armatures and a machine switch and field rheostat for each exciter. The generator panels each contain an oil machine switch and two triple pole, single throw quick break knife switches for connecting the generator with either of two sets of busbars. There are also an indicating wattmeter and an ammeter in the generator circuit, and an ammeter in the field circuit. The handle of the field rheostat is removed from the board and placed on an iron standard, five feet from and directly in front of each panel. There is also a synchronizing plug and lamp and a voltmeter plug on each panel.

The two transformer panels each contain an oil switch capable of breaking 1500 K. W. at 800 volts, a 3-phase recording wattmeter, an ammeter and a voltmeter which is provided with a compensating shunt which can be so adjusted as to cut down its indicated voltage, in the same proportion as the reactance and resistance of the transmission line reduces the voltage at the receiving end. Thus the voltage at the substation in St. Paul is constantly before the operator at the generating station regardless of the power factor or drop in the line.

The station panel is equipped with a triple pole, double throw switch for connecting it to either set of busbars. On it are also mounted, the switch for the electric heaters, the induction motors that drive the blowers for the transformers, and the incandscent and arc lighting circuits.

The transformers consist of two banks of three, each transformer having a capacity of 500 K. W. The secondaries are connected in delta and the primaries in star, raising the voltage from 800 to 25000.

They rest on a wooden floor supported by I beams over an air chamber, four feet deep, which gives an unrestricted distribution of air from the blowers to the transformers, also providing easy access to the lower terminals and the heavy 800-volt cables, which are supported on wooden horses and porcelain insulators.

Two independent blowers are provided, each capable of supplying both banks of transformers. These are belted to two 220 volt 5 H. P. induction motors, which are supplied from two independent sets of two transformers connected in delta with one side left out.

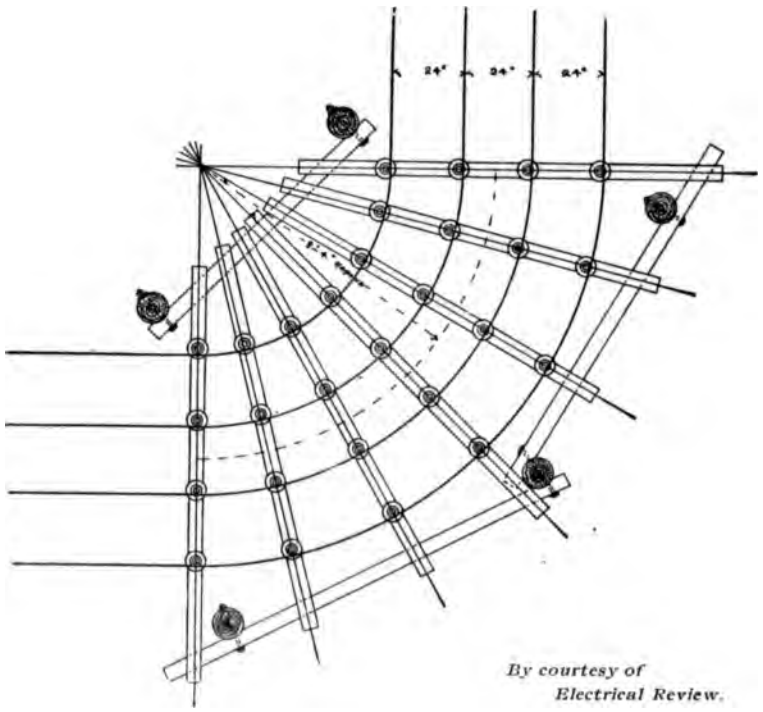
In starting and testing alternators that are to be operated in parallel, some method is necessary for determining if the phases in the several machines are connected in the same rotation, before they can be synchronized. This was easily accomplished in this case by connecting each machine separately to one of these motors. If all the phases are connected in the same rotation, the motor always revolves in one direction. The 25000-volt side of the transformers are connected to a high potential switchboard, equipped with nine Westinghouse high tension circuit breakers, or switchers. These are each mounted on a marble slab, 48 inches long by 10 wide, the switch terminals being 40 inches apart. The slabs are supported on heavy porcelain insulators, in an iron frame. The switches are spaced 25 inches between centers, separated by marble barriers, 59 inches by 51 inches by 1 inch.

These switches consist of two hardwood poles, one six feet long and the other four feet. The longer one has two spring clamps fitting over the switch terminals; the shorter is hinged to the other at the lower switch terminal and connected to that terminal by a flexible wire which passes through its interior to the upper end, which can be swung up and connected to the upper terminal by a short fuse or wire which is fastened through a carbon contact by a screw to the shorter pole and a cam clamp on the other. This clamp can be tripped by pulling a cord and the breaker used as a switch; a spring at the bottom of the short pole throws it away as soon as released. The switches can be both opened and closed under full pressure without danger to the operator. When opened under full load, they draw out an arc about 36 inches long and reaching only 4 to 6 inches above the path followed by the contact point. There are three switches in each circuit and three in a cross connection between the two circuits.

From this board the wires pass through 10-inch holes in the end wall of the power house into the lightning arrester house, where a choke coil of 40 turns is inserted in each line. Outside of these are installed the arresters, which consist of 12 2000-volt General Electric arresters in series for each line wire. These are mounted on hard rubber boxes on marble panels. The ground connection consists of a copper plate, one and one-half inches wide by one-sixteenth inch thick, connected with large copper plates in the river. From the arresters the wires pass directly to the overhead line, which is 24½ miles long and ends in a similar lightning arrester house in St. Paul, at the beginning of three miles of underground cables which complete the connection with the distributing station. The overhead line consists of two independent 3-wire 3-phase circuits, carried on one set of poles, one circuit on each side. The three wires arranged at the vertices of an equilateral triangle with 24 inch sides. The wires are No. 2 B. & S. copper, supported on triple petticoated glass insulators, 7 inches in diameter, known as "Prevo" type. The cross arms are of Ore-

gon fir. The pins are special locust, with 1¾-inch butts. The poles are of cedar ranging from 30 to 60 feet in length and with 8-inch tops. The maximum distance between poles being 110 feet.

In line construction the ideal is, for obvious reasons, a straight line over a smooth country, and the production of a line free from all possibility of interruptions, both in regard to its surroundings, and in its structural features. In practice these points are necessarily compromised on account of engineering difficulties or financial necessities. Such as the acquisition of proper rights of way, the crossing of rivers, lakes or swamps, mountains, or inaccessible sections where construction and maintenance are both of a difficult nature.



SPECIAL CORNER CONSTRUCTION.

In cases of this kind it will often be found cheaper to make a detour of the obstacle than to go over or through it. In an ordinary line the cost of construction, of poles, etc., will vary directly as the length, and the cost of the copper, directly as the square of the length, thus a rough estimate on the ground, will generally decide which is advisable. Angles are always a source of weakness and should be eliminated as far as possible.

The principle engineering difficulty experienced in the construction of the aerial line was the crossing of the St. Croix river, a stream about one-half a mile wide with precipitous banks 100 to 150 feet high. Advantage was, however, taken of a railway bridge already construct-

ed, and the line was attached to it, by placing 8x8-inch oak timbers between the ties and allowing them to extend over on one side for 20 feet, both circuits being transposed three times in the length of the bridge, in order to nullify the inductive effects of iron. Outside of this one circuit is transposed twice during its length, and the other runs straight through without transposition except on the bridge.

Wherever acute angles were encountered a special construction was made. By investigation it was found that the pins were the weakest elements in the construction. The special constructions were,

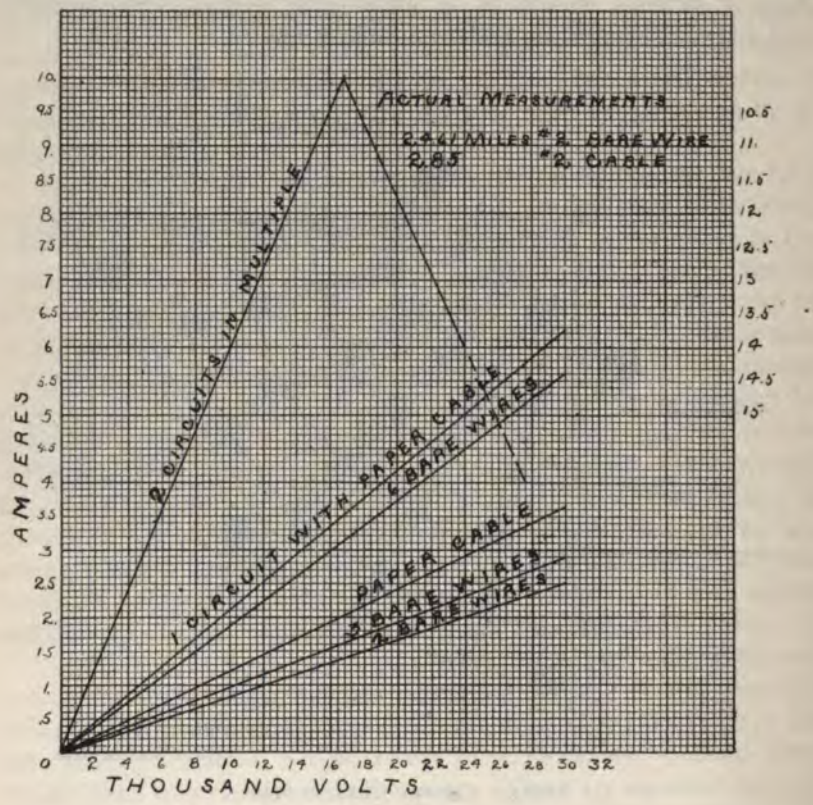

ACTUAL MEASUREMENTS
2.96 MILES
2.85
#2 BARE WIRE
#2 CABLE
2 CIRCUITS IN MULTIPLE
1 CIRCUIT WITH PAPER CABLE & BARE WIRES
PAPER CABLE & BARE WIRES
2 BARE WIRES
AMPERES
THOUSAND VOLTS
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
10.5 11. 11.5 12. 12.5 13 13.5 14 14.5 15

FIG. 1.

therefore, designed to give added strength in this particular. The wires not changing direction at any one pin by more than 15°. At the terminals a strong 4-pole construction is made with eight pins and insulators in line for each wire, thus securely anchoring the line.

At the St. Paul terminal of the aerial line the wires pass from the lightning arresters directly to the heads of the underground cables. These are carried in 4-hole McRoy vitrified clay conduits, laid in concrete.

One of the cables, the "National," is insulated with paper treated with a secrete insulating compound. Its thickness around each conductor

is 9-32 inch and around the whole three is wrapped a jacket of paper ⅛ inch in thickness. The whole is covered with a lead sheath, with an exterior coating of tin.

The other cable, the "Safety" is insulated with rubber 7-32 inch in thickness around each conductor, the three wrapped with a drilled tape served with jute, making a jacket 5-32 inch in thickness, covered in turn with a lead sheathing containing 3 per cent. of tin.

The first tests of the line were to ascertain whether it would stand

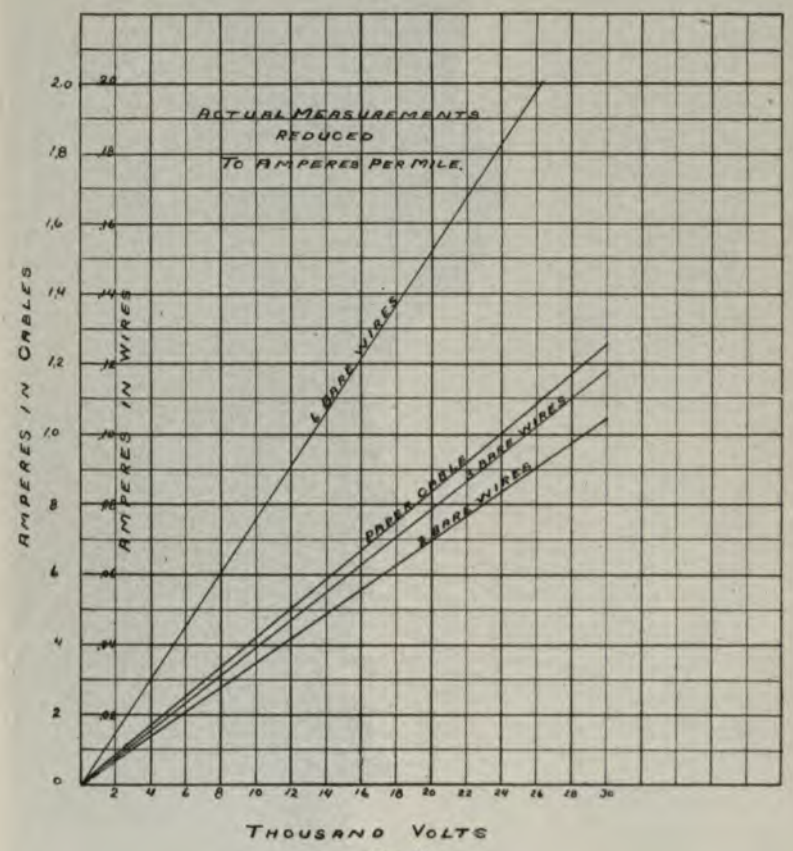


FIG. 2.

the high voltage, which was gradually raised to 30,000 volts, without the breaking down of the insulation at any point.

Later it was tested to determine the charging current of the different lines and cables. This was done by placing a low-reading ammeter in the high tension circuit, and connecting a Weston voltmeter to the secondaries of a 25,000 to 125-volt transformers, both instruments being recently calibrated. The speed of the generator was kept constant at 300 giving 60 cycles per second. Readings of the current were taken for different voltages and combinations of circuits.

The results were plotted and shown in Fig. 1. The changing current for one line was found to be practically the same as the other. Also that there was no appreciable change in the reading for one line, if both ends of the other line were free, or whether the wires were tied together and connected to the ground.

Fig. 2 shows the actual measurements reduced to amperes per mile. The rubber cable is shown to take practically twice as much charging current as the paper cable, this is probably due to the character of its dielectric.

VIEW FROM TOP OF ARMORY, UNIVERSITY OF MINNESOTA.

From the "University Souvenir" by courtesy of H. W. Wilson.

THE DEVELOPMENT OF THE STEAM HOT BLAST SYSTEM OF HEATING AND VENTILATION.

A Nontechnical Description of the Subject.

B. S. Harrison, S. B.

There was a time not long since, when school boards and building committees for state and other public buildings, were content to provide for the heating of such buildings by the cheapest possible means (cheapest in first cost), and paid little or no attention to the quantity or quality of air to be supplied for ventilation, the cost of maintenance and operation, or the life of the system.

Those were the days of the hot air furnace which still holds sway in country districts and in many small private buildings, even in the cities; and than which, there is no system of heating and ventilating more expensive per pound weight of apparatus furnished.

But the better and more conscientious class of heating engineers, even in those days, realized the unreliability of the furnace for heat and its total inadequacy as a ventilating agency due to its dependency upon winds, temperature of outside air and other atmospheric conditions which interfered with its action.

Direct and indirect radiation, with so-called natural ventilation was a vast improvement over the furnace system in every way, but they also were subject to the same conditions for ventilation, though not to the same extent. On a muggy day, with a medium temperature and a high relative humidity, a room crowded with people needs to have its ventilating apparatus working at its best. It is obvious that if the outside temperature is 65° F. and the radiation from the occupants of the room raises the temperature to 70° F., or over, to give the indirect radiators full steam in order to force the ventilation would simply make a bad condition worse by increasing the temperature still more, while an aspirating coil in the vent stack would be a very expensive expedient.

The result of these observations was the introduction of the Steam Hot Blast System. At first this system consisted of a fan, or blower, in the basement, which drew its air from some outside source and forced it through a main heater group, directly in front of it. Fan and heater were encased in a sheet steel case, and the heat flues to the different rooms were connected to the hot chamber side of the coil case by galvanized iron trunk lines ramifying to them. The ventilation then became mechanical, and could not be controlled, as far as the amount of air handled by the system was concerned, regardless of

whether the whole heater group were under steam, or only a part of it, or none at all. The registers opening into the rooms were operated by hand.

It is easily seen that by such an arrangement the engineer in charge would have to be very attentive, that not too much or too little steam were supplied to the heater, for if the air were delivered too hot, the occupants of the rooms would partly or entirely close the registers in those rooms and the ventilation would be interfered with.

To overcome this feature, a separate set of air ducts was added to the system, taking its air from the mouth of the fan, on the cold air side of the heater group and connecting to the different hot air risers or flues.

A hand damper was placed at the junction of the hot and cold air connections with the vertical flues, and operated by means of a chain and pull in the room above.

The damper was weighted so that in its normal position it shut off the cold air and allowed the hot air to enter the flue. When the pull in the room was drawn and adjusted on pins set in a wall plate, this damper raised, shutting off the hot air and admitting a quantity of cold air proportionate to the amount of hot air shut off. When the hot air was entirely shut off, the cold air connection was wide open. The result may be imagined. While the amount of air admitted to the rooms was approximately a constant quantity, the sudden change in temperature caused immediate and noticeable drafts. The hot air inlets into the rooms, being at a height of about eight feet above the floor, on the wall, the heated air entered the room above the level of the occupants' heads with a tendency to rise. The continued admission of more warm air forced it gradually toward the floor as a layer, until it reached the level of the vent register at the floor, and directly underneath the warm air inlet, when it was forced out.

But when the cold air, at the zero point or lower, was suddenly admitted, its tendency was to drop. An unstable equilibrium was caused, resulting in sudden descents of cold air which were annoying and dangerous. It was attempted to overcome this by reducing the area of the cold air ducts to one-half, but this reduced the evil less in proportion than it did the ventilation.

Then a new and successful change was tried. It was noticed that during weather of from 60° F. up, these noticeable drafts disappeared. A tempering coil was placed in the suction chamber of the fan so that in cold weather the air might be 'tempered' to about 60° F. before being handled by the fan. Thus the air delivered to the rooms could never be colder than 60° F.

In order to control this temperature of the incoming air more easily, and avoid heating it too much before it reached the main heater group or "reheater" (as it is now called), a by-pass damper was placed underneath, or at one side of the tempering coil. It was so

arranged that part of the air could be drawn through the tempering coil and part through the by-pass, without being tempered; or the whole of it by-passed, as desired.

At this time the Automatic or Thermostatic Regulator came into the field and did much to improve the system. A change was also made in the manner of connecting the heat flues or risers to the pressure chambers or plenum chambers.

Instead of carrying a hot and a tempered air connection from these chambers to each flue, and having the mixing damper at the base of the flue, a single galvanized iron connection was carried to each flue. At the heater end it opened into both the hot and tempered air chambers of the heater case, with a butterfly damper in each opening. These two dampers were connected by a link in such manner that, as one closed the other opened and the amount of air supplied to the pipe was always the same. The thermostat itself was placed in the room to be regulated, and, being of the "graduated movement" type, kept the mixing dampers gradually moving back and forth until the exact position was found at which the right proportions of tempered and hot air were admitted to hold the temperature of the room at the desired point.

By uniting the currents of air at the heater case instead of at the base of the heat flue, as by the old method, they tended to mix in the horizontal pipe or connection, and enter the room at an average temperature.

The reheater group was divided into four sections, the steam supply to each being controlled by a thermostat regulated globe valve and a globe hand valve.

The steam supply to the tempering coil was also placed under thermostatic regulation, and the tempering coil by-pass.

The by-pass thermostat was the same type as used in the rooms, but those controlling the steam connections were of the positive action type (totally opened or totally closed). The thermostat controlling the steam to the tempering coil and the by-pass, were placed in the tempered air chamber. Those controlling the steam supply to the reheater sections were placed in the fresh air inlet, and regulated the steam supply according to the outside temperature.

The operation began somewhat as follows: At any outside temperature below —20° F. the whole system received steam and the by-pass was closed; at —20° F. one reheater section was turned off; at +5° F. the second reheater section was turned off; at +35° F. the third reheater section was turned off; at 45° F. the tempering coil by-pass opened, admitting part of the fresh air untempered; at +60° F. the tempering coil was shut off, and at +70° F. the last heater section closed. By this arrangement the operation of the whole system became almost entirely automatic, and as register screens without valves

were now used in the warm air openings into the rooms, the occupants could not interfere with ventilation by closing or opening.

When a steam engine was used to drive the blower, the exhaust was passed through the heater section whose thermostat would close it off last, or at +70° F. In this way the exhaust steam would never be turned into the vapor pipe until all other sources of steam supply as heat were shut off, thus avoiding any waste of steam.

The section receiving this exhaust is usually the first section in front of the fan, as there it receives the air direct from the tempering coils and thus receiving the blast of air direct from the fan it will condense from one-third to one-half more steam than the last coil in the reheater group. It has been tried, putting the exhaust into the tempering coil, but in cold climates the condensation is apt to be sudden enough to freeze up the coil.

The only remaining difficulty in the system has been met within the last few years in several different and successful manners. This difficulty or condition, was the dust which is always drawn in by a fan and delivered through the system unless taken out by some sort of filter.

What has appeared, both in theory and practice to be the most successful solution of this question, is virtually an air laundrying device. It consists of a spray chamber with vertical and horizontal rows of spray nozzles through which the fresh air supply to the fan, is drawn, after it leaves the tempering coils. The spray nozzles are all adjusted and when properly set, give off a perpetual fine spray or mist. Any dust or other foreign substance in the air passing through is moistened and precipitated into a drip pan or tank in the floor of the chamber.

This tank is at all times partly filled with water, which by means of a circulating pump, is being used over and over in the sprays.

The sprayed air, on leaving this wash chamber must be deprived of its moisture before being passed through the fan or delivered to the rooms. It is drawn through a series of slightly conical tubes, which are about sixteen inches in diameter at the suction end and about fourteen inches at the delivering end. Through each tube runs a spiral rib which gives the current of air passing through, a rotary motion. This centrifugal action throws any moisture present upon the sides of the tubes where it is drained off by means of small drip holes, and carried back to the drip tank.

The air leaves these tubes cleansed and dried and enters the fan pure and fresh.

Further improvements will be made upon all systems of heating and ventilating including the hot blast system, but at the present time there is no other system which can accomplish the same results during all conditions of weather.

It has its modified forms and every heating engineer worthy of the title uses it in some of its modifications. There is hardly a public building of any size or importance in course of construction in the large cities where Steam Hot Blast is not being installed, either in whole or in part.

Like any other really good mechanical arrangement, if improperly designed or faultily installed, it can cause an immense amount of trouble, and will be found expensive of operation; but when laid out by a competent engineer, well installed, and properly operated it performs its work with an economy which is impossible to approach with any other system.

RECENT DEVELOPMENTS IN ARC LIGHTING.

GEO. D. SHEPARDSON.

Progress is generally by waves. Sometimes there is rapid advance, and then come times of apparent quiescence or even retrograde movement. The history of arc lighting is of this sort. When Davy first discovered the arc in 1802, he was encouraged to further experiment and in 1810, with the financial help of others, he exhibited a strong arc light that dazzled the members of the Royal Institution in London. Primary batteries were far too expensive to allow the arc light to pass from the laboratory, but the development of the dynamo provided a source of cheaper electric power, and in 1863 the arc lamp was introduced to practical work in some of the French lighthouses. The Centennial Exposition at Philadelphia, in 1876, witnessed not only the first public exhibition of the telephone (N. Y. Elec. Engineer, v. 15: 128), but also the first exhibition of an arc lighting system in which more than one arc lamp could be operated continuously from a single dynamo. Wallace, who made the dynamos for lighting the Centennial grounds, succeeded in a few years in making several arc lamps operate in series, making the first public exhibition at the American Institute Fair in 1879. Brush was working at the same problem and it is a question whether he or Wallace was the first to operate arc lamps successfully in the same series circuit. Brush was the first to bring out the arc lamp with series and shunt coils, the combination which alone made it possible to operate a large number of arc lights in series. The honor of having the first central station for public lighting by arcs is divided between Cleveland and San Francisco. A company was incorporated in June, 1879, in the latter city and the lighting station was burned up on April 24, 1880. One of the great attractions of Paris in 1880 was the fact that one of its avenues was lighted by arc lamps, the Jablochkoff candle. The silent admiration with which I viewed those magnificent spheres of light has not diminished to this day. What can be more beautiful than the dazzling splendor of a bare arc? While later developments have made the arc more useful for general illumination, yet no artificial light in use can equal the majesty of a row of bare arc lights illuminating a large area. The enclosed arc and the incandescent lamp may give more satisfactory illumination, and in many cases the lights themselves may give as satisfactory appearance as the bare arcs. But for giving the impression of greatness and of inspiring the satisfaction of basking in the presence of a light almost supernatural, nothing can rival the bare arc.

The Brush lamp of 1879 was followed by those of other inventors, with or without real improvement. The great advances were made in the dynamo machines for generating the current. From the machine of 1879, capable of operating two or four lamps in as many circuits, Brush developed a gigantic machine capable of furnishing current for sixteen arc lamps. Soon after came the sixty-four lighter, then the ninety lighter, and now for several years machines for one hundred and sixty lamps each have been in use in considerable numbers. The power required for operating the machines has increased correspondingly from about one to one hundred horsepower.

For a number of years practice was divided between "high tension" and "low tension" systems, the former using a current of between nine and ten amperes with forty-five to fifty volts at each lamp, the latter using fifteen to twenty-five amperes and about thirty volts at each lamp. The principal argument in favor of the low tension systems was the lower voltage on the circuits and the smaller danger to life and property. Since with a given size of conductor, the line loss is proportional to the square of the current, and since there was found to be practically as good illumination with one as with the other, and further, since it was found that the low tension system was capable of giving shocks hard enough for undertakers' purposes, the high tension system held the field. Custom soon adopted the Brush practice and the standard current became 9.6 amperes and the lamps were adjusted to take 45 to 50 volts at the arc.

Dazzled by the intense light, the arc was claimed to give two thousand candle power, and this name has persisted. The actual amount of light is much less. The stock joke perpetrated in all seriousness is that the lamp gives five hundred candlepower toward the north, an equal amount toward the east, south and west, making a total of two thousand. The designation of "nominal 2,000 c. p." was soon adopted in self defense. Frequent disputes and lawsuits led to the adoption by the National Electric Light Association of a definition which might avoid any disputes. It was found that the actual amount of light given out by an arc lamp varied with the current, the voltage, the diameter and quality of carbon and the kind and cleanness of the globe. The strength of the light also varies in different directions. The simplest definition which seemed acceptable was on the basis of the electrical energy absorbed and to-day it is the general practice to settle disputes by determining the energy. The arc light of two thousand nominal candlepower is one which absorbs four hundred and fifty watts at the arc. The demand for arc lights requiring less power than the "full arc," brought out the "half arc" of twelve hundred nominal candlepower. The N. E. L. A. has not defined this lamp, but on a proportional basis, it is expected to take about three hundred and eighty watts. This lamp was operated on series circuits carrying six to six and eight-tenths amperes, the lamps being adjusted to the same

voltage as for full current, that is, forty-five to fifty or fifty-five volts. The actual amount of light delivered from the "half arc" was much less than that from the full arc. But since the latter gave more than was needed, and since the half arc gave nearly equal brilliancy and looked nearly as large and effective as the full arc, while requiring less investment for fuel and equipment at the power house, the half arc came into great favor with small towns and cities. Where arc lamps are placed more than two blocks apart, they serve more as beacons to indicate directions of streets than as lights to make the roadway visible, and for such use the half arc is fully as effective as the full arc.

For street lighting, where long distances are met, the series system is admirably adapted; the same current passes through each lamp, the addition or removal of lamps simply requires an adjustment of the total voltage at the dynamo, extra lamps can be put in at any point without affecting other lamps. Similar advantages appear for operating commercial lamps, that is, lamps for lighting interiors for private customers, and the series system found large use in this field. But the bringing of high voltages into buildings where the wires or lamps might easily be touched, introduced an element of danger to person and property. Another difficulty was that some customers wanted the lights for longer or shorter hours than the average, and the difficulty of metering the energy on the arc circuit left without an alternative the flat rate system of charging. When customers could be classified and arranged on circuits which started and shut off at about the hours desired, this was fairly satisfactory.

The desirability of having a light always ready for use at any hour of day or night, of having only low voltage circuits in buildings, of having everything on meters so that a customer paid only for what he wanted and used, and the desirability of having all lights on the same set of wires, led to the development of the arc lamp for incandescent circuits, that is, an arc lamp which would operate satisfactorily when connected between wires maintained at a nearly constant difference of potential. One of the earliest of the successful constant potential arc lamps was the Ward lamp, two of which helped light the University machine shop for several years. The constant potential arc lamp rapidly drove out the constant current lamp from commercial circuits and also found a large field among those who had not cared to have the high tension circuits brought into their premises.

One of the large items in the expense of keeping up an arc light is the cost of the carbon pencils and of the trimmer who replaces them and cleans the globes. Attempts were early made to increase the life of the carbons by increasing their length or diameter. Others attempted to exclude the air so as to minimize the atmospheric combustion. The first practical success was attained by Howard and Marks, being announced at the International Electrical Congress at

the Chicago World's Fair, in 1893. The new lamp won its way slowly but surely, and to-day practically all of the arc lamps sold are of the enclosed type. It is found to effect a saving of several dollars per annum per lamp in the cost of carbons and trimming. The enclosed arc lamp has another advantage, in that it operates at seventy to ninety-five or even one hundred sixty volts at the arc. For operating on circuits, of about one hundred volts, it had been necessary to connect two arc lamps in series or to waste half of the energy in dead resistance when the open arcs of forty-five or fifty volts were used. The enclosed lamp can be operated singly across the same circuit with no greater loss than was formerly entailed, and thus is available in many places where two lamps are not desired. A single enclosed lamp can also be operated successfully on two hundred twenty volt circuits, although better light is given when two eighty-volt lamps are operated in series. The single lamp with one hundred sixty volts at the arc gives a light with a violet tinge that is not so satisfactory as that from the lamp taking twice the current at half the voltage. The enclosed arc lamp found a large field in connection with alternating current circuits. There is comparatively little difficulty in operating arc lamps on direct current circuits, but with alternating currents the arc was found to make a noise which was objectionable. When, however, the arc was enclosed in a tight glass globe, the noise was diminished and was muffled to such an extent that it was nearly inaudible.

Having made a success for interior work on constant potential circuits, it was applied to series circuits for street lighting with considerable success. While the total amount of light from an enclosed arc lamp is less than that from an open arc taking equal energy, the light is distributed more uniformly, avoiding the intense shadows usual with open arcs. Having the apparent source of light a comparatively large globe instead of the small arc, the intensity is not so great, and the arc does not blind one so much as does the open arc. The result is that while the total amount of light from the enclosed arc is less than that from the open, the light is applied more usefully, the traveler's eyes are opened to the full extent and he can see the roadway better than with the more dazzling open arc. Since the enclosed arc takes only six amperes instead of nine or ten, the line loss is less, or the lines may be of smaller wire. On the other hand, the voltage runs up higher and it is not uncommon to find ten thousand volts or higher on series circuits with enclosed arcs. This involves difficulties in insulation and maintenance which offset the smaller line loss.

On account of the difficulties in maintaining insulation and safety to life and property with the high voltages encountered with arc dynamos, their size is limited commercially to about one hundred horsepower. With constant potential circuits, on the other hand, generators of more than a thousand horsepower are the usual thing in stations of any considerable size. The large machines cost less than do

small ones of equal aggregate capacity, they require less space in the station, their efficiency is higher so that smaller engine and boiler power are required, they need less care from the operators, and in every way are preferable. The problem was therefore to use the same generators for all purposes, supplying incandescent and arc lamps and motors from the one set of bus-bars. The tendency is growing for the large stations to use large alternating current generators and to operate arc lamps from these. The direct current arc is more efficient than the alternating, and it is desirable to use it when other conditions allow. Some stations operate induction alternating current motors, driving direct current arc dynamos. A common practice in England is to use a rectifier to change the alternating to direct current. A common practice in America is to use alternating current lamps which take enough current to give equal light with the direct current enclosed arc lamp. In each case the problem is complicated and it is difficult to decide what is the best solution in any particular case.

ARMORY, UNIVERSITY OF MINNESOTA.

From the "University Souvenir" by courtesy of H. W. Wilson.

METHODS OF GETTING INTO AND OUT OF MINES.

BY ARTHUR EDWIN HAYNES.

The history of mining thus far presents various ways of getting into and out of mines. For convenience of reference they may be enumerated as:

(a) By "adits"; (b) by steps cut in the rock; (c) by steps cut in the rock for *ascending* and "slides" for *descending;* (d) by bucket (wood or iron) attached to rope and windlass or hoisting drum; (e) by ladders (with wood or iron rungs); (f) by "skip," running on inclined track, and drawn by a steel wire rope, passing around a hoisting-drum, run by an engine; (g) by man-car, running and propelled as in (f); (h) by the so-called "man-engine," and (i) by cage.*

Method (a) is possible only where the mine is worked by means of "adit levels" or horizontal shafts, as is the case where a shaft or tunnel is constructed horizontally into a bluff or a mountain. In such cases the miners have only to walk into or out of the mine on the roadway of the tunnel. Such mines are, however, the exception. I know of but one "adit" in the famous "copper region" of Michigan, where most of my knowledge of such matters was gained by observation and experience, during three years of service at the Michigan Mining College. This "adit" was constructed by the Quincy Mine, at Hancock, but its use was discontinued long ago.

Method (b), an old method, is sometimes used where the slope of the shaft is not more than 40 or 50 degrees and where the rock is sufficiently firm.

Method (c) is also used under similar conditions and where "slides" can be constructed, down which the miner may be carried by gravity, as on a toboggan, the slope being from 30° to 50°, but gradually flattening near the bottom, in order to diminish the velocity.

Method (d) viz: by wood or iron bucket, capable of containing one or several men, I have frequently seen used in this "copper region," but mostly in sinking shafts, as in the construction of the Whiting shaft of the famous Calumet and Hecla mine. This method is not to be commended for safety. During my residence in the immediate vicinity of these mines, I had the pleasure of making trips into and out of several of them by each of the following methods. Method

* Since the preparation of this article, I have been informed by Mr. J. F. Orr, who has recently been a mining engineer in Mexico, that some very primitive methods of getting into and out of mines are still in operation there. Poles, with notches cut in them, are used in descending, and ascending, they are called "chicken ladders."

In other places where the shafts are not too steeply inclined poles are fastened, at equal distances, on the foot wall of the slope at right angles to its length, thus forming a series of steps or a sort of ladder resting on the rock up which the miners pass with the ore in leather bags carried on their backs.

(e) which simply consists in descending or ascending ladders in passing from one level to another. This method is rather slow and somewhat dangerous, because of the liability of slipping and it must be tedious to the tired miner, as he takes his homeward journey at the close of the shift or day's work. Method (f) viz: by "skip," is easier and more rapid than the preceding, and as one does not have to expend his own energy in making the descent or ascent it is much more comfortable, but it is not comparable in comfort with method (g) viz: by

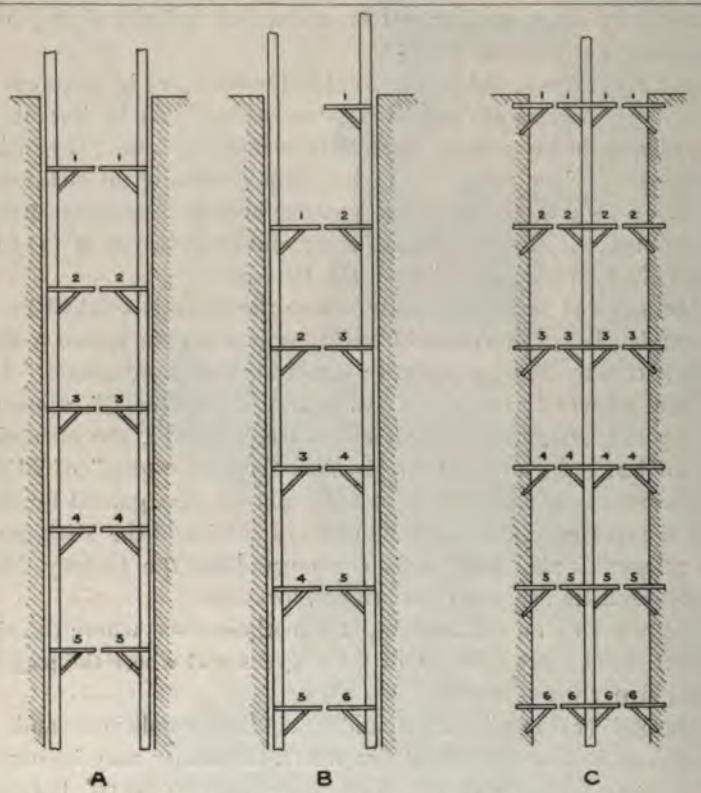


Fig. I. A. and B. represent a double-rod man-engine.

A. Shows the relative position of the rods before the stroke begins.

B. Shows the rods at the end of a downward stroke of the first rod.

C. Represents a single-rod man-engine. In either case, the miner, in descending, steps onto the platform numbered (1) as the rod begins its downward stroke; at the end of the stroke he steps off onto (2) in the double-rod engine, just as it begins its downward motion, and so is carried to (3), of the first rod, etc. In the single-rod engine he waits on (2), of the shaft, until (2) of the *rod* begins its downward motion, when he steps on to it, and is carried to (3) of the shaft, etc.

Fig. 11. Front view of a part of the man-engine of the Quincy mine.

man-car, which is a car made to run on an inclined track with horizontal seats arranged like a set of stairs on which as many as thirty men may be seated and rapidly let down or brought up. The Quincy mine has within the past five years adopted this method in its four double shafts, and now consumes only from 30 to 40 minutes in taking its force of nearly eight hundred men into or out of the mine. Each car makes a trip, nearly 3,600 feet in about six minutes. This method is much cheaper, quicker and safer than the next method (h) by man-engine, which is given a place here because on several occasions, at the Quincy mine, it has safely carried me nearly 3,000 feet below the rocky surface of the earth and with equal safety brought me up from these rocky, weird, cavernous depths into the free air and sunlight again. At that time I was informed that it was the only engine of the kind used in that region; again I speak of it here for the sake of completeness, for its historic interest and because of its quite recent use in some of the mines of this country. For example, it was only in August of 1895 that its use ceased in the Quincy mine, where it was displaced by the man-car, as I have been recently informed by Capt. Thos. Whittle, of that mine, who compares the man-engine in its slowness of operation to the ox cart. Compared with more modern methods, it possesses little practical value, and its use has been substantially abandoned. There are two varieties of the man-engine, the "double rod" and the "single rod"; the "double rod" was invented first. The first engine of this kind was put into operation in the Harz (or Hartz) (N. W. Germany) in 1833; nine years after a similar machine was put into the Tresavean mine in Cornwall, England; it has also been used in Belgium and Westphalia. This method is less safe than by ladders. While it is slow in its operation, yet it possesses an advantage in being adapted to inclined and even crooked shafts, and this is no doubt the reason why it has been, so often, used in mines without vertical shafts. The "double rod" man-engine consists of two jointed "rods" on timbers, running on rolls or trucks; these rods are placed parallel and near together, they bear, at equal intervals, horizontal platforms (sollars); these platforms usually have a guard rail around three sides, being open on the side toward the other platform. The timbers or "rods" bearing these platforms are given a reciprocating motion, like the rods of a pump, by a surface power plant, the stroke being from four to sixteen feet, but, of course, always being of uniform length with any given engine.

The engine to which I have before alluded had a one hundred horse power plant, its stroke was ten feet and it made about ten strokes per minute, thus it will be seen that it took about a half hour for a man to go to the bottom of the shaft (3,150 feet) and the same time to return.

The reciprocating motion is best given by means of a crank; for it is thus gradually slowed down at the dead points, giving the miner a

Fig. III. Side view of a part of the man-engine of the Quincy mine, showing "balance bobs," on the thirty-fourth level.

better opportunity to step across from the platform, on one rod to that on the other. The "single rod" engine of this kind has the steps on the rod as on each rod of the "double rod" engine, and then there are permanent, or fixed platforms at equal distances on either or both sides of the shaft.

In both of these engines at the beginning or end of a stroke the corresponding platforms are opposite each other, between strokes the platforms on the rods are in motion.

In the double rod engine (see figures) when the miner wishes to enter the mine he descends the shaft by stepping on to a platform just as the engine is beginning its downward stroke, he is then carried down until he reaches the end of the stroke when he steps across on to the platform which is now immediately opposite on the other rod, just in time to catch its downward stroke, and so he alternates back and forth, being constantly carried deeper. When he wishes to return to the surface, he reverses the process, or simply gets on to a platform as the rod begins its *upward* stroke. Of course, in either case, a whole shift of men may follow each other in succession, finally, if there is a sufficient number, making a line of men, equally spaced, from the surface to the bottom of the shaft.

It is an interesting sight to look down into the dark depths of the shaft and see the line of candles in the hats of the miners as it swings back and forth, almost with the regularity of a pendulum, as a shift is going to or returning from its work. I shall not soon forget the thrill of joy that came to me, when I came up on the engine to which I have before referred about half the three thousand feet without any candle, as I first caught sight of the glimmering daylight at the mouth of the shaft. Nor shall I soon cease to recall the heavy manly, bass voice of the mining captain (Whittle) on the platforms above me, as he called out at the end of each stroke, "change," in order to aid those below in stepping safely from the platforms of one rod to those of the other.

In the "single rod" engine, in descending, the miner takes a platform of the rod on its downward stroke, steps off on to the first permanent platform on the side of the shaft and waits until the next downward stroke, when he again steps on to a platform of the rod and is carried down again the length of the stroke. In ascending he reverses the process as in the other engine. In the use of this engine, however, he may take successively all the platforms on one side of the shaft, and so, if the platforms are large enough, one shift of men may be descending while another is ascending. Like a pump rod the rods of the man engine require proper "balance bobs" and catches to enhance the safety of its use. The time of descent or ascent, as I have indicated before, depends upon the length and time of the stroke: for example, if each stroke is twelve feet and there are five strokes per minute it will take thirty minutes to descend eighteen hundred feet.

Fig. IV. Two quadruple-decked cages. Parrott (copper) mine, Butte, Montana.

The relative expense of raising and lowering men by this method is large and does not compare favorably with the more modern methods. For example: at Dalacoath, a tin mine in Cornwall, nearly 2,400 feet deep, it is reckoned that 1½d. or about three cents per day, per man, covers all expense, including interest on capital expended and depreciation of the plant. But the time gained by these modern methods is of much importance; for instance, the change made in the Quincy, five years since, from the man-engine to the man-car enables the management of the mine to get from one to two hours more work in each shift. When a mine has reached a depth of say 600 or more feet, mechanical appliances should be used for raising or lowering the men in order to save both time and the strength of the men.

The medical profession are also agreed that excessive ladder-climbing is injurious to the health of the miner. Therefore, for both hygienic and financial reasons one of the first thoughts in working a mine should be the conveyance of the men up and down the shaft by machinery with the least possible fatigue, expense and time and with maximum safety.

The last method (i) of which I shall speak, viz: that by cage, possesses, I believe, all of these advantages. Of course this applies to vertical and other shafts in which it may be successfully worked. This method consists of a cage of one or more compartments, covered with a steel shield, running between guides and having automatic safety catches. This cage is run up or down the shaft by means of a steel wire rope attached to its cross beam and wound around a hoisting-drum, to which steam or electric power is applied. Electric power for this purpose is rapidly coming into use in the West, because of its easy transmission from points removed at considerable distances from the mine. By this method men may be safely lowered or raised at the velocity of 1,000 feet or more a minute. In fact, on Feb. 18, 1893, with Capt. Jas. Werne, in this manner I came up the shaft of the "Tamarack Junior," 3,000 feet, in about one minute without any discomfort.

The size, number, depth (some of them nearly a mile) and great expense of the vertical shafts, in and about the Calumet and Hecla, and Tamarack mines of the upper Peninsula of Michigan, are, to me, a constant wonder. A visit to the surface plants and the underground workings of the mines of this celebrated region is worth a journey across the continent. Here, whether one be interested in either mechanical or mining engineering, he may find some of the grandest illustrations of each to be found anywhere in the world.

NOTE.—The photographs from which the half-tones, Figs. II, III and IV, were made, were kindly loaned by the Minnesota School of Mines, of this University.

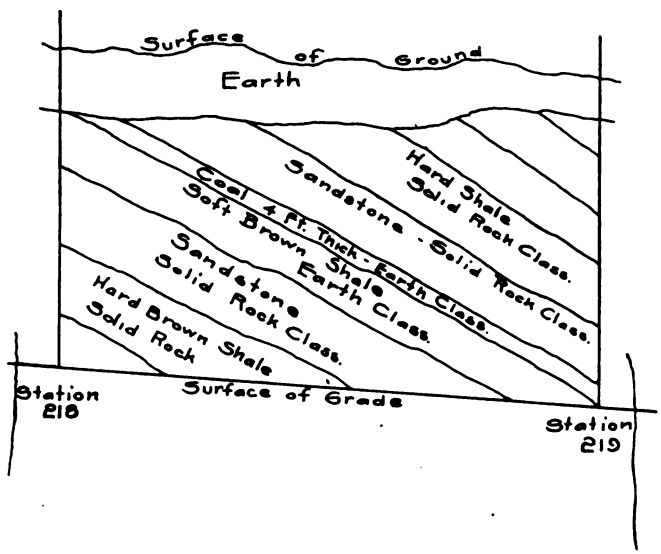
SOMES NOTES ON THE CLASSIFICATION OF MATERIAL AND SHRINKAGE IN EMBANKMENTS.

C. E. CROWNOVER.

In ordinary railroad construction the classification of material, and the allowance for shrinkage in embankments presents no difficult problems. In excavation, the earth can usually be taken off first, and a new set of cross-sections made for the rock. The embankments are usually not so high or so long, but that the ordinary method of increasing the height as an allowance for shrinkage can be made.

Where material of different classification is found in layers of such thickness that several of them may be gone through at one cut-

FIGURE 1



ting of a steam shovel, a more difficult problem is presented. In the case of a high embankment, where it is desired to run trains as soon as the work is completed, increasing the height, as an allowance for shrinkage, is impracticable.

The Union Pacific railroad has recently completed, on its main line in Wyoming, some work in which these difficulties were encountered. It is known by those familiar with it as the "Dana Hanna Cut," and the Dana-"Hanna Fill," being a part of a cut-off between the towns of Dana and Hanna.

The excavation begins at station 200 and ends at station 254. Here the embankment begins and its end is at station 274. The great-

est depth of excavation is 62 feet, and the greatest height of embankment is 101 feet. Stating it in round numbers, the excavation is one mile long by 60 feet deep, and the embankment is nearly one-half mile long by 100 feet high.

The test pits showed that all the material below the first covering of earth could not have one classification. Each layer could not be stripped off separately, so that it at once became evident that some other means of arriving at the classification must be adopted.

The covering of earth was of different thicknesses. In some places rock would show on the surface, while at others the earth was as much as 15 feet in thickness. Under the earth covering were found solid rock, hard shale, soft shale and coal in layers varying in thickness from two feet to ten and twelve feet. The dip of the strata was about thirty degrees with the horizontal.

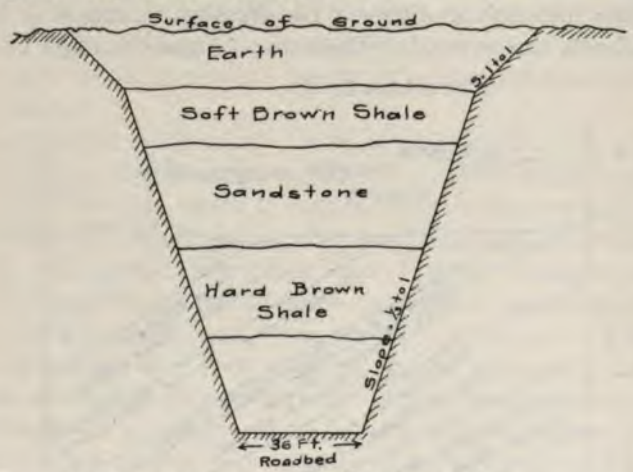


FIG. 2.

A center line was kept staked in the cut so that accurate notes could be taken for classification purposes. The exact depth of the beginning and ending of each layer at every cross-section, the station number of the outcroppings of every seam, the station number where it intersected the roadbed, and wherever a seam changed in thickness, the amount of change and the station number were noted. After the excavation was completed and the slopes dressed, these notes were verified by an examination of the slopes. The notes were then platted to a large scale (one-fifth the usual profile scale) on profile paper, making three profiles, one on each of the sides and the center. Figure 1 is a sketch of a station 100 feet long of one of these classification profiles.

This information was also platted on cross-section paper. Figure 2 is a sketch showing the cross section at station 218 with the classification shown.

Only two classifications were made, viz.: Earth and rock. The percentage of each was determined by a study of the volume between any two adjacent cross-sections. The rock predominated so that all the material not classified as earth was called rock. For example, take the volume between the two adjacent cross-sections 218 and 219, as shown in figure 1. Suppose we wish to find the volume of the layer of soft brown shale. From figure 1 we can either compute or scale its average length and its average depth. From figure 2 we get in the same manner its width. From these three dimensions we have its volume in cubic yards. Treating each one of the layers that we decide shall be classified as earth in the same manner, and combining their contents, we have the number of cubic yards of earth in the prismoid. Subtracting this from the total volume of the prismoid gives the yardage of rock. Studying each section separately, then combining gives the total yardage of each earth and rock, and thus an exact percentage of each.

This method has the disadvantage that it requires constant supervision by one who is experienced in the classification of materials. Even then it is very probable that it will pay in work of much size. This one excavation had about 330,000 cubic yards. The contractor guessed that it was 90 per cent rock and insisted that he be paid accordingly. The figures gave a trifle over 70 per cent rock. Taking 65 cents as an average difference in the price of earth and rock gives a difference of about $34,000, or a saving to the company of that amount.

SHRINKAGE.

Where shrinkage is taken into account in small embankments they are built above grade an amount equal to what they are expected to settle. Then when settlement has taken place the surface will be at grade.

Even in small embankments this is theoretically an impossibility owing to the uneven settlement, but is practicable because the surface after settlement will not be so uneven but that it can be levelled off when the roadbed is surfaced for the ties.

Most text books that give rules on this subject say that the height of embankments shall be increased a certain percentage, depending upon the nature of the material and the manner of construction. Now the inexperienced engineer, in staking his first embankment, would probably interpret this to mean that the allowance must be made in setting the slope stakes. To illustrate, if the fill were 10 feet, and the shrinkage 10 per cent, he would probably stake it as an 11 foot fill. The quantities would show the true amount put in, and if it were paid for in embankment the contractor would be paid for putting on the shrinkage.

As a matter of fact no account of shrinkage is made until the final grades are set. Then the proper amount is added to the height, the

material allowed to roll down until it reaches the toe of the slope. It will not go beyond unless of very coarse material, such as boulders.

Finishing with this kind of material is usually forbidden. Since the settlement is only vertical it is only necessary to make allowance in this direction. The roadbed is made the proper width on top, so that when settlement has taken place the embankment will have the required slope. In this case the quantities shown by the cross-sections are those after settlement, so that the contractor is not paid for putting on the extra amount for shrinkage. Most railroad companies pay for excavation only, so that the matter of price would not be considered. In the case of the large embankment described with a shrinkage of 7 per cent, if this method had been adopted the height would have been 107 feet or 7 feet above grade. Had this been done and the fill al-

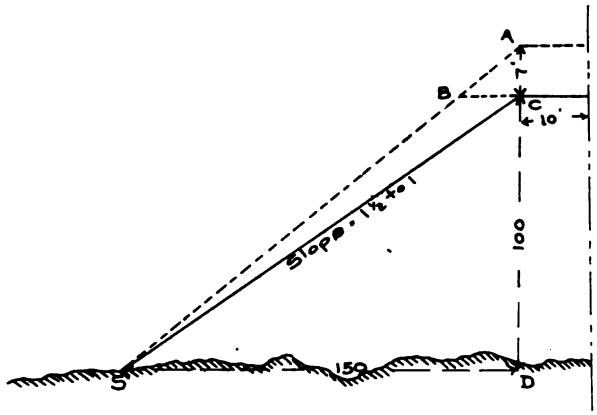


FIG. 3.

lowed to stand for several years before running trains, it is doubtful if the surface would have settled to anywhere near the true grade.

Owing to the different kinds of material and the manner of building it was quite certain that no law of settlement could be depended upon.

The base for a height of several feet was made with slips and wheelers from a borrow pit. The remainder hauled by train from the cut before described. Earth and rock were all dumped in together as it came from the cut. Being filled from a temporary trestle only one side could be built up at a time. All these circumstances made an even settlement impossible.

The method adopted was as follows. Instead of increasing the height the banks were widened to that extent as to be the same width as if the height was increased 7 per cent. Then as settlement slowly takes place, material can be added on top to bring the roadbed up to

grade. The top is of sufficient width that the embankment when carried up gradually as the settlement requires, will have the proper width of roadbed.

The full lines in figure 3 represent the cross-section of an embankment 100 feet high, finished up to grade with roadbed 20 feet wide and slopes 1½ to 1. The dotted line as it would appear, if it were increased 7 per cent in height. Now instead of building the bank up to the dotted line, it was only built up to grade and widened out to the dotted slope line. The amount represented by the triangle SBC in figure 3 was added on. This increased the slope from SC to BC, but not enough to hinder the placing of the material. Eventually it will settle to the line SC and will then have the required slope.

Referring again to Figure 3, we have from the similar triangles, ABC and ASD:

$$SD : BC = AD : AC \text{ or}$$
$$150 \times BC = 107 : 7$$
$$BC = 9.8$$

which is the amount to be added to the half width of roadbed. In the above embankment 100 feet high and roadbed 20 feet wide the width on top was $20 + (2 \times 9.8) = 39.6$ feet.

Let us see how much this would actually increase the volume. The volume of a 100-foot fill for 100 feet for a 20-foot roadbed and 1½ to 1 slopes is 62,963 cubic yards. The volume with banks widened to 39.6 feet is 66,592 cubic yards, an increase of a little less than 6 per cent in terms of the smaller volume.

Taking the case of a one-foot fill, we have the following:

$$1.5 : x = 1.07 : 0.07$$
$$x = 0.098 \text{ feet},$$

or, for every one foot additional height, 0.098 of a foot should be added to the one-half width of roadbed, or practically for every foot in height, increase the width by 0.2 of a foot.

Note—Since writing the above, Mr. L. B. Merriam has an article in the Engineering News of January 3, 1901, on the subject of shrinkage. It was under his supervision that the work referred to in Wyoming was done. C. E. C.

NOTES FROM SNOQUALMIE FALLS.

VERNIE GRAYLING.

This station is equipped with four Westinghouse 3 phase generators, rated at 1500 K. W., 1000 volts, 60 cycles, 300 R. P. M. The generators are provided with Doble water wheel sets of 2500 H. P. capacity. The head of water is 260 feet. There are two transmission lines to Seattle and two lines to Tacoma, the transmission voltage being 30,000 volts when generator voltage is 1000. The station is underground.

For a long while there were no governors on wheels, and the regulation was very poor, especially when a rotary converter was put on and used for street car work. In case of a short circuit, anywhere, which would open breakers here on feeder panels, it was necessary to depend on a rheostat to hold the speed down while shutting the water off the wheels. One set of feeder panels was used for the rheostats or "tanks," as they were commonly called. These were good for the full capacity of one machine and connected so one, two or three of them could be put in as desired and taken out by tripping the breaker on each panel. A new rheostat is now being built of No. 2 B. & S. G. iron wire to be made in three sections so that when all three sections are in it is a delta connection on the busbar. Each section is made up of 20 coils of 100 turns per coil. The coils were wound with a 2-inch inner diameter and those of each section, in series, mounted on a wooden frame using porcelain insulators. The three sections are placed in one tank, which is kept filled with running water, supplied by an iron pipe. This rheostat is supposed to absorb 2500 H. P. at 1000 volts. Such a rheostat is very effective and necessary where suitable governors are not in use. The operator can notice a load drop off and get in a "tank" before the oiler would notice the machines speed up. These tanks have come in very handily several times, especially when loads of 1500 or 2000 K. W. have been dropped off.

The next thing which attracted attention was difficulty with the generator bearings caused by a stray current between the shaft and shells of bearings. During the early summer only one unit was running. The generator was equipped with a 1000 H. P. Pelton wheel. There was a stray current in the generator bearings, being worse at the collector ring bearing than at the other bearing. On the other side of the machine from collector rings were the two water wheel bearings which carried off some of the strong current and thus lessened the amount of it in that bearing on generator. At the collector ring bearing a spring was fastened to frame of machine and a contact on end of it

made contact at center of shaft and this carried off quite a lot of the current and helped the bearing some, but it was necessary to scrape the boxes and polish the shaft quite often to avoid excessive heating. The boxes and shaft soon became pitted up in bad shape. The current seemed to be D. C. and of low voltage. This unit was No. 4.

Later on No. 3 generator was started up, having been equipped with a 2500 H. P. set of Doble wheels. This machine of course carried a heavier load than No. 4, and the stray current was worse and there was sparking between the oil rings and shaft at the collector ring bearing.

Some time after this Nos. 1 and 2 generators, having been equipped with Doble wheels, were started. To dry out the armature the generator leads were short-circuited and a very weak field put on generator. About 700 amperes per phase was the result at any speed between 200 and 300 R. P. M. This soon dried the armature out, but on No. 2 caused such excessive sparking at oil rings in collector ring bearing that the oil was soon burned and a good deal of oil thrown out of bearing. The oil soon turned black and had a burned smell. There was not much trouble on No. 1 generator. When there is a sparking between oil rings and shaft the oil rings always carry an unusually large amount of oil.

One day the oiler discovered sparks jumping between armature and a pole piece on No. 2 generator. We immediately took the load off of generator preparatory to shutting it down, and as the load became light this sparking ceased, and we saw it was caused by a small piece of metal hanging down from pole piece and touching armature core. This piece of metal was an iron chipping ¾-inch long and ⅛-inch square and afforded a path for the stray current between the core and frame of machine.

A short time after this occurrence the coupling bearing on No. 2 generator got hot and began to smoke. The oil rings were carrying an abundance of oil at the time, but the oil was black, having been burned. The next day, when the bearings were over-hauled, it was found that the collector ring bearing was in worse shape than the one which heated. At the collector ring bearing the sparking between oil rings and shaft had been so excessive that there were two grooves, at least 1/16 inch deep, worn in shaft where oil rings turned. The shaft on No. 3 generator was in the same condition. The bearings and shafts were pitted up in bad shape.

These troubles soon caused an investigation to be begun. Many noted men of both the Westinghouse Co. and of the General Electric Co. looked things over. Some said the stray current was generated in the armature. The armature is 8 feet diameter, and the core contains a very large mass of iron. The armature complete weighs eleven tons. There are 38 1-inch steel bolts which hold the laminations of

the armature core together and it was suggested that these augmented the difficulty.

Some experiments were tried and it was found that the voltage on shaft around the armature and outside the generator bearings was as high as 5 volts A. C. and sometimes 1 volt D. C. Some times being D. C. and not A. C. and vice versa. The theory was then proposed that the generator leads, which go down under one section of the frame, gave a series transformer action. These leads were above the frame on No. 4 generator when the trouble first began.

This stray current seems to be worse on one machine at one time and then on another machine at another time. The cavity has a large steel receiver and a good deal of metal in wheels, etc., and some seem to think that this and possibly some local magnetic effect may help in generating this stray current.

Attaching a wire to frame of machine and touching other end of wire to end of shaft a heavy current flows through the wire, as it has less resistance than the film of oil between shaft and shell of bearings. A current of several hundred amperes may pass through a large wire at times of heavy loads or large armature current.

The Westinghouse Co. then came forward with a theory which seems to be the correct one. The armature is delta connected and is tapped at two places on the collector ring side. The third tap was taken off of armature on the other side and brought through the spider close to the rim, then down on to the hub and to its collector ring. In this way this third tap with the armature conductors made nearly a complete turn around the armature core, thus giving the transformer action. This tap, on all four generators, was changed to the same side of armature as the other two and all sparking at oil rings ceased and there seems to be no current in bearings.

This was certainly a very serious matter. New shafts would have been needed in a short time. It required lots of oil as the oil when black had to be taken out and fresh oil put in, using not less than one or two barrels of oil per week.

Most transmission plants using as high tension as 30,000 volts have probably had more or less line trouble at one time or another. This plant certainly has had. On the Tacoma line there was some trouble on account of too small wire and the poles being spaced too far apart. This wire, which was aluminum, was replaced by aluminum cable. It was necessary to use copper wire in the city limits of Seattle and Tacoma. Most of the lines are of aluminum wire.

Fortunately there is no lightning, or at least not enough to cause any trouble. There was a very heavy damp snow at one time which piled up on the cross arms and insulators but gave no trouble. Once a wire came untied and rested on cross arm. In a short time the feeder breakers on this line opened. When the breakers were put back in there was no trouble till the voltage got to a certain point and then

the breakers would open. There was some trouble on account of wind blowing the wires together. Once, with the two Tacoma lines in parallel, one line broke. The feeder ammeters showed 2200 amperes per leg and the generator nearly stopped.

It might be best to give an outline of circuits, etc. There are 12-555 K. W. oil cooled transformers, grouped in four sets of three each. Each transformer has a separate feeder panel, numbered the same as transformer. On each feeder panel is an automatic circuit breaker, usually set to go at 1200 amperes, ammeter and a double pole double throw switch so as to use on either set of busbars. The ammeter does not read the current in each transformer, but that from each leg of busbar. In the transformer house there is a high tension plug board, such that any line can be connected to any set of transformers or any combination desired. Each transformer has two high tension fuse switches and each line has three similar switches. The lines are designated as Seattle 1, 2, 3 and 4, 5, 6 and Tacoma 1, 2, 3 and 4, 5, 6. The usual method of running some time ago was to have T. (Tacoma) lines 4, 5, 6 on transformers 4, 5, 6, S. (Seattle) lines 1, 2, 3 on transformers 7, 8, 9 and S. lines 4, 5, 6 on transformers 10, 11, 12. The S. lines 1, 2, 3 were used for rotary converters and fed from lower busbar, while the other two lines were used for lighting and fed from top busbar.

The generator voltage was usually between 900 and 1000 volts to suit the demand at the Seattle substation. In the early summer the transformers were connected for 15,000 volts. There was a good deal of trouble on account of rotary pumping badly, but since the transformers were connected for 30,000 volts there has been no trouble on account of pumping.

One Sunday morning we had occasion to shut down the machine used on lighting circuits and these lines were to be put on lower busbar with rotary. As the first swithch (No. 4) of the Tacoma transformers was put in breakers 7, 8, 9 opened. Towards evening transformers 10, 11, 12 were put back on top busbar and then transformers 4, 5, 6 were to be put on top busbar. As the first Tacoma switch (No. 6) was put in breakers 10, 11, 12 opened. As we could find no cause for the breakers opening we concluded it to be due to putting the Tacoma line on when the voltage was fairly high. The usual method of putting on a dead line is to lower the voltage considerably before closing the transformer switches, but in these cases it could not be done. This same trouble happened several times.

The trouble was thought to be at the lightning arresters in high tension lines, and so a series of experiments were conducted to find out. Men were assigned to watch the arresters while tests were being made. The Seattle lines were put in parallel at substation and all lines fed from top busbar. The first experiments were tried on about 27,000 volts. The rotary was put on, running empty with a heavy

lagging current. Then the Tacoma switches 4, 5, 6 were opened and closed several times, but none of the breakers opened. The rotary was then taken off and the Seattle substation operator was to take out the high tension switches to his transformer. As he took out the last high tension transformer switch breakers 7, 8, 9 and 10, 11, 12 opened. This experiment was repeated with the same result. As the breakers opened there was a discharge at the lightning arresters here and at Seattle.

The lines were then put back on and rotary put on. It was the intention to take out the Tacoma high tension switches here. As the second Tacoma high tension switch was opened breakers 7, 8, 9 and 10 11, 12 opened. There was a discharge at lightning arresters here and at Seattle. The lines were put back on and rotary left off. The Tacoma high tension switches were opened and closed several times, and no breakers opened. The rotary was then put on again and as the second Tacoma high tension switch was opened breakers 8, 9 and 10, 11, 12 opened, but No. 7 breaker stayed in. The rotary being on one phase, began to pump violently. This breaker was tripped at once to save rotary, but not in time, as the brass bands, which hold the field coils, were pulled down into the armature, being twisted and broken, and the collector rings were blistered up in bad shape. When the breakers opened a discharge was noticed at the lightning arresters at Seattle.

For the next experiments the Seattle lines were separated at substation and all line switches at Seattle and Tacoma were taken out, thus leaving the lines free of every thing except the raising transformers. All lines were fed from top busbar and the voltage raised to 33,000 volts here. When the Tacoma high tension switches were opened breakers 7, 8, 9 opened. The field ammeter on generator swung through a range of 50 amperes when breakers opened. The lines were then put on again and the experiment repeated with the same result. There was a discharge at lightning arresters in Seattle. The lines were then put on and as the first Seattle high tension switch was taken out breakers 7, 8, 9 and 10, 11, 12 opened. There was a heavy discharge at lightning arresters in Seattle. The ground wire to the lightning arresters at Seattle was then disconnected and lines put back on and voltage raised to 30,000 volts. The Seattle high tension switches were taken out and put back in and no breakers opened. The voltage was raised to 33,000 volts and the Seattle high tension switches were taken out and there was no trouble, but as they were put back in breakers 4, 5, 6 opened for the first time. There was a discharge at lightning arresters in Tacoma and a static discharge off the lightning arrester panels in Seattle. The ground wire to lightning arresters at Tacoma was then disconnected. The lines were then put on and voltage raised to 33,000 volts. Lines were taken off and put on but no breakers opened.

Being thus convinced that the difficulty was in the lightning arresters, the ground wires at Seattle and Tacoma were left disconnected, but those here were left connected and there has been no trouble since then in putting on or taking off lines here or at the substations. It was decided that there were not enough spark gaps at lightning arresters or else they were not clean enough.

Before these experiments were conducted the lines were connected up as follows: Falls to Seattle on S. lines 1, 2, 3 and return on S. lines 4, 5, 6 thence to Tacoma on T. lines 1, 2, 3 and return on T. lines 4, 5, 6. There was a set of transformers on each end of the line and none at the substations except at times. The line, thus connected, was about 153 miles long. The resistance of one wire of line was measured and found to be 241 ohms. All readings were taken at switch board and there were no instruments in high tension line.

With this line open at returning end it was found that the feeder breakers would open at from 34,800 to 35,100 volts, due to current pumping across spark gaps at lightning arresters.

One of the generators was synchronized in at the end of line as a synchronous motor. At times it would pump violently. When the frequency was 60 the frequency of the oscillations of ammeter needles was 80. The field ammeters on generator and motor would swing about a good deal. When the water was cut off of generator suddenly the fly wheel effect of the motor armature would cause it to generate, feeding into the line.

With a non-inductive load at end of the line 1100 K. W. were sent out and 723 K. W. returning as load or a loss of 34.2%.

Some of the data of test is given below:

Amps. per Phase	E. M. F. Impressed	Field Current	Kilo Volt Amps.	K. W. Wattmeter	Periodicity	Power Factor	E. M. F. Line	E. M. F. Terminal	LOAD
Alternations Constant. Varying E. M. F. Transformers in circuit with their secondary open.									
350.	750	55	453	76	7200	.168	22500	24600	Charging Current Only.
406.6	841	62	554	84	7200	.153	25300	27400	
506.6	1000	80	877	123	7200	.110	30000	32100	
Alternations Constant. Varying E. M. F. Open circuit.									
386.	753	55	402	62	7200	.154	22700	.....	Charging Current Only.
406.6	826	60	582	75	7200	.128	24800	.....	
525.	1000	79	908	112	7200	.123	30000	....	
640.	1160	110	1285	175	7200	.134	34800	.....	
651.6	1170	112	1320	180	7200	.134	35100	....	
Alternations Varying. Constant E. M. F. Open circuit.									
406.6	1000	100	705	100	6000	.141	30000	....	Charging Current Only.
473.	1000	90	820	105	6600	.128	30000	....	
525.	1000	79	908	112	7200	.123	30000	.....	
578.	1000	75	1000	115	7800	.115	30000	....	
Load—Rheostats on end of line.									Amps. E. M. F. K. W.
630.	1000	93	1117	1095	7200	.98	30000	22800	550 760 721
525.	820	.....	744	695	7200	.92	24600	18600	475 620 530
Transformers Cut in at Seattle and Tacoma. S-7, T-4. Their secondary open.									
407.	1000	84	704	192	7200	.274	30000	31500	

RULES GOVERNING THE WIDTH OF LEATHER BELTING.

BY J. J. FLATHER.

The problems in belting, although apparently simple, are in reality so complicated, and so many considerations are involved in their solution, that we are not surprised at the multiplicity of varying rules and formulæ by which the power transmitted by a given belt may be obtained.

There are in general five principal considerations which should obtain in determining the size of belt, viz., coefficient of friction, arc of contact, speed of belt, strength of belt per square inch of section and durability.

Experimental work has usually been directed to determine the coefficient of friction, and it has been shown by exhaustive tests that the coefficient of friction, ϕ, of leather belting on smooth cast-iron pulleys may vary from 12 per cent. to 165 per cent., depending upon so many factors that it is impossible to so correlate them as to determne accurately what the coefficient may be in any given case.

In general we may say that the value of the coefficient depends upon the nature and condition of the leather, the percentage of slip, temperature and humidity, and probably pressure.

The velocity of sliding, which influences the friction more than any other factor, is directly proportional to the belt speed, and may safely be estimated at one per cent. of the speed per pulley, that is two per cent. for each pair of pulleys. The maximum slip permissible with horizontal belts is about 20 per cent.; a greater slip than this is liable to throw the belt off.

For the past 25 years the coefficient of Towne & Briggs, viz., 42 per cent., has generally been accepted by engineers, but this was deduced from the results of experiments having a large slip (200 feet per minute), which gave the coefficient equal to 0.58, so that the value recommended is only 0.70 of that obtained by experiment. Even with this allowance it is probable that the value is somewhat higher than average practice would warrant. With percentages of slip varying from 0.8 to 2 per cent., Mr. Lewis finds the coefficient to vary from 0.25 to 1.38, the first value being obtained for a percentage of slip equal to 1.5, and the second for a slip of 1.7 per cent. Two per cent. slip gave $\phi = 0.45$. Other experimenters find that ϕ varies from 0.12 to 0.58, depending principally upon the rate of slip.

Prof. Lanza's numerous tests made at the Massachusetts Institute of Technology indicate that 27 per cent. is the most suitable value to use for a low rate of slip. His results were obtained on belts running

about 1,500 feet per minute and with a slip of about three feet per minute.

Regarding the strength of belting, as might be expected, this is extremely variable. Kirkaldy's tests, which cover a wide range, show the strength to vary from 2,000 to 6,000 pounds per square inch of section.

The various tests indicate that double belts are superior to single, both in respect to their greater uniformity and also a lesser liability to become crooked by reason of uneven stretching due, probably, to the fact that the former are composed of two layers, which tend to neutralize any local imperfections occurring in either. It is evident that the strength of a belt cannot be stronger than that of the joint. We cemented joints the splice, if properly made, is not materially weaker than the body of the belt; with riveted joints the ultimate strength, as given by Towne, is 1,750 pounds per square inch and for laced belts 960 pounds.

Prof. Walter Flint, of Maine State College, finds that metal belt fasteners may cause the joints to fail at from one-fourth to one-half the strength of solid belt, and that laced joints may rupture under a stress of 30 per cent. to 80 per cent. strength of solid belt.

In existing belt transmissions the stress per square inch of section is extremely variable, ranging from 30 to 1,200 pounds per square inch. The reasons for this are two-fold: First, a superior quality of leather will permit a greater stress without undue trouble and expense in repairs; and secondly, some belts are calculated to transmit a stress greatly in excess of that to which they are actually subjected.

A feature often neglected in the ordinary formulæ is that of durability of the belts. F. W. Taylor, in his "Notes on Belting," states that "the one consideration which should have more weight than all others in making up tables and rules for the use and care of belting is how to secure the least possible interruption to manufacture from this source."

In calculating the total expense of belting and the manufacturing cost chargeable to this account, it has been observed that by far the largest item is the time lost on the machines while the belts are being relaced and repaired; especially is this true in those establishments where the running of a series of machines is dependent one upon another, the stoppage of one machine involves delays on others.

The results of Mr. Taylor's observations on belting, covering a period of nine years, constitute a valuable compendium on the subject and should be carefully studied. Among many interesting conclusions we note the following:

(a) The belt speed for maximum economy should be from 4,000 to 4,500 feet per minute.

(b) Belts are more durable and work more satisfactorily made narrow and thick rather than wide and thin.

(c) It is advisable to use double belts on pulleys 12 inches in diameter or larger and triple belts on pulleys 20 inches in diameter or larger.

(d) All belts should be cemented instead of laced or fastened in any other way.

(e) When a belt is spliced the tension used should be ascertained by means of a spring balance connected to belt clamps.

(f) The total life of belting, cost of maintenance and repairs, and the interruption to manufacture caused by belts are dependent upon the total load to which the belts are subjected more than upon any other condition. The other conditions are: Method of splicing, care in properly greasing and keeping them clean and free from machine oil, and the speed at which they run. This latter has little effect under 2,500 feet per minute.

(g) The total stretch of leather belting certainly exceeds six per cent. of its original length.

(h) Oak-tanned and fulled belts are superior in all respects (except co-efficient of friction) to either the oak-tanned not fulled, the semi-rawhide, or rawhide with tanned face.

(i) If double leather belts are tightened while at rest 71 pounds per inch of width, and subjected to an additional working load of 65 pounds per inch of width, their tension will fall in 2½ months so as to be, while at rest 33 pounds per inch width, or 106 pounds per square inch section; their average tension during these 2½ months being 46 pounds per inch width, or 150 pounds per square inch section; their average load during these 2½ months being 111 pounds per inch width, or 358 pounds per square inch of section. These are the conditions under which belts work when tightened according to the ordinary rules.

(j) The most economical average total load for double belting is 65 to 73 pounds per inch of width; *i. e.*, 200 to 225 pounds per square inch of section.

(k) A double belt having an arc of contact of 180 degrees will give an effective pull of 35 pounds per inch width for an oak-tanned fulled belt, and 30 pounds for other leather belts and 6 to 7-ply rubber belts; or 950 feet per minute of one inch wide oak-tanned and fulled belt will transmit one horse power, and 1,100 feet per minute of other leather belting and 6 to 7-ply rubber.

(l) Belts should be cleaned and greased every five to six months.

A glance at some of the existing belt formulæ shows that the older millwrights frequently allowed 550 feet per minute for a single belt—only 25 per cent. of that given in section (k), for ordinary belting.

The probable reason for the satisfactory running of these belts has already been pointed out, viz., overrating the capacity of the machine and estimating upon a horse power three or four times greater than actually required.

Some of the more recent rules used by shopmen assume that a single belt one inch wide will transmit one horse power for every 800 to 1,100 feet per minute; Mr. Taylor's rule, it will be noted, calls for a double belt of the same width.

While the conclusions arrived at by Mr. Taylor are extremely valuable from an engineering as well as commercial standpoint, the first cost of equipping a plant under his rules would often prohibit the use of such heavy belts; moreover, in many situations it is probable that equally satisfactory results are obtained under stresses twice as great as those given, especially in those cases where the belt runs at moderate speed over a pair of approximately equal pulleys of large diameter, and is not shifted from one pulley to another. On the other hand, the conditions might be such as to call for certain belts fully as wide if not wider than those given by Mr. Taylor's rules.

Such a case might arise when running at a high belt speed from a very large to a very small pulley (or *vice versa*) with the tight side of the belt on top; in this case the centrifugal force would diminish the effective tension, the arc of contact would be lessened, and the adhesion of the thick belt on the small pulley would not be as effective owing to imperfect contact, due both to air entrainment and to a wrinkled belt produced by bending; all of these would necessitate an increased width of belt.

Owing to these various causes it is impracticable to determine a general formula which will be applicable in all cases. We may, however, suggest limitations. As someone has aptly remarked, a significant factor (which, however, cannot enter algebraically into the equation), is the judgment of the designer.

In the following discussion a formula is obtained which, by proper choice of constants (to be selected for any particular case when the data are known), will give a suitable belt width, considering durability and expense of operation, under those conditions which are liable to arise in ordinary practice.

Assuming that the driving force P is equal to the difference in tension T_1 on the driving side of the belt and T_2 on the driven side, and noting that the driving force must equal the friction between the surfaces, we obtain $T_1 - T_2 = P = F$.

The friction F depends upon the arc of contact, α, between the belt and pulley, the coefficient, Φ, and upon the centrifugal force, F_0, set up in the belt, due to its velocity and weight; it is, however, independent of the diameter of pulley. To determine the values of F, T_1 and T_2, it will be necessary to assume a given tension in the belt; also its speed and weight, coefficient of friction and arc of contact.

Let u = friction between element of belt and pulley;

p = normal pressure exerted by element on pulley;

f = allowable working stress in the belt;

=265 pounds per square inch for laced and 350 pounds per square inch for cemented joints;

v=velocity of belt in feet per second;

w=weight of belt per unit length and area;

=0.41 pounds per square inch section one foot long;

b=breadth of belt;

t=thickness of belt;

A=area of cross-section of belt;

F_0=centrifugal force due to speed and weight of unit length;

R=radius of pulley;

T=tension in belt at any point;

T_1=tension in belt on tight side;

T_2=tension in belt on slack side;

V=velocity of belt in feet per minute;

α=least arc of contact—circular measure;

=0.0175 times arc in degrees (α^0);

Φ=coefficient of friction=0.27 for small slip and ordinary good belting.

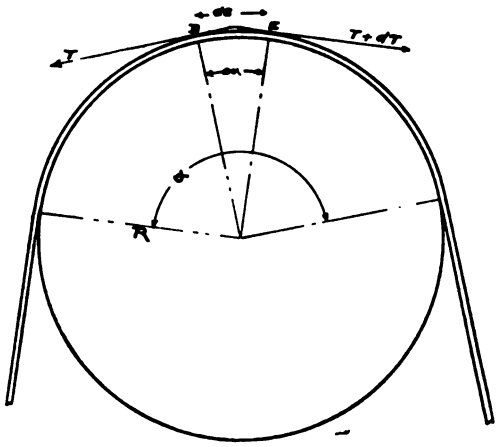
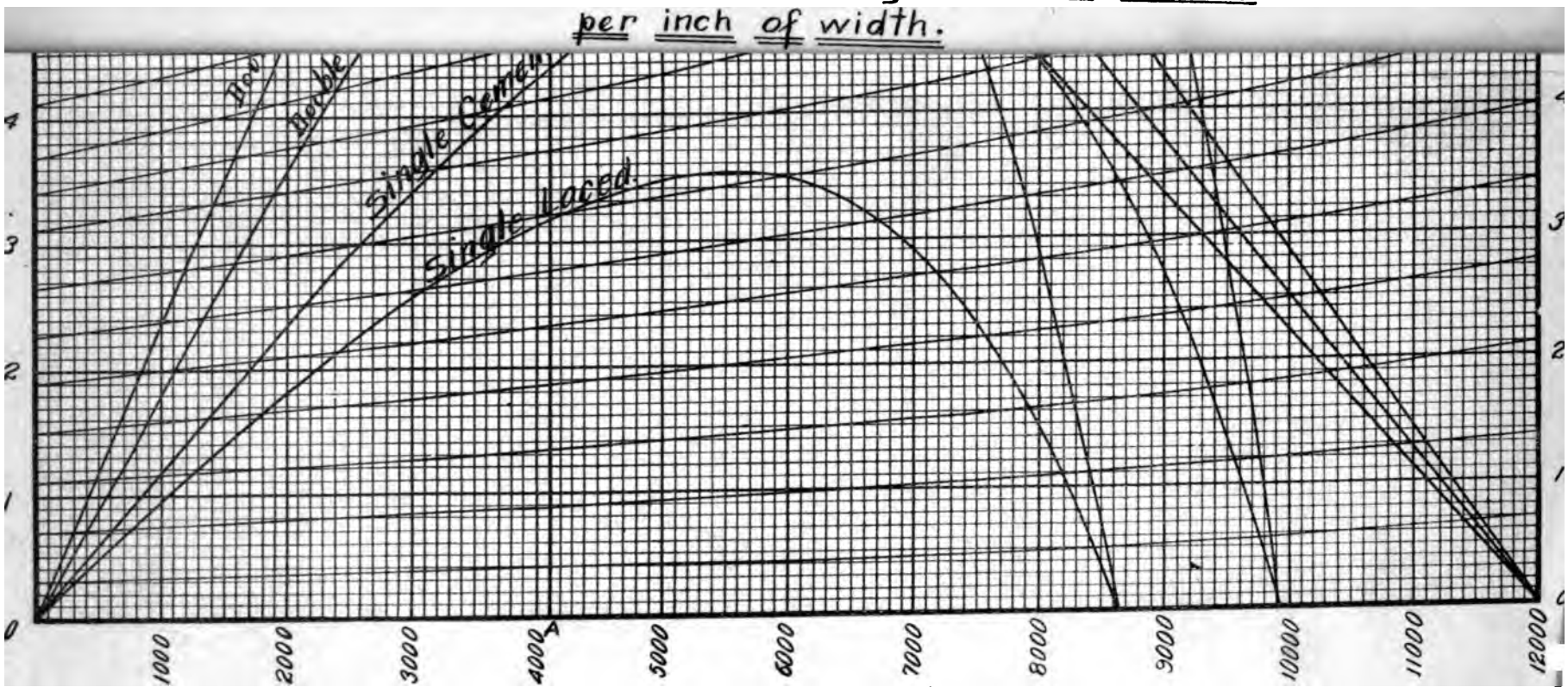


FIG. I.

If, in Fig. 1, T is the tension in the rope at any point D, then the tension at the point E, whose distance from D is ds, will be $T+dT$. Assuming u to represent the friction on the element DE, we shall have $u=dT$ when the several forces are in equilibrium. Since the friction is dependent upon the normal pressure, p, exerted by the element upon the rim of the pulley, and since this normal pressure is diminished by the centrifugal force due to the weight and velocity of the element, we shall have $dT=(p-F_0)$. For the present we shall neglect F_0. Now p is the resultant of the two forces T and $T+dT$; hence

$$p = T \sin \frac{d\alpha}{2} + (T + dT) \sin \frac{d\alpha}{2}$$

Horse Power Transmitted by Leather Belts, per inch of width.



Velocity of belt in feet per minute.

which may be assumed equal to $T d\alpha$ on account of the smallness of $d\alpha$ and dT; therefore

$$dT = \Phi\, T d\alpha \text{ or}$$

$$\frac{dT}{T} = \Phi d\alpha \tag{1}$$

Integrating we have

$$\int_{T_2}^{T_1} \frac{dT}{T} = \Phi \int_0^{\alpha} d\alpha \tag{2}$$

$$\text{hyplog}\frac{T_1}{T_2} = \Phi\alpha \text{ or } \frac{T_1}{T_2} = \varepsilon^{\Phi\alpha}; \text{ therefore} \tag{3}$$

$$T_1 = T_2\,(\varepsilon^{\Phi\alpha}) \text{ and } T_1 - T_2 = P = T_2\,(\varepsilon^{\Phi\alpha} - 1) \tag{4}$$

If we assume that the working tension per square inch of a leather belt (cemented joint) equals 350 pounds, a convenient value will be obtained for f and one which will give satisfactory results when the belts are properly cared for.

For laced joints three-fourths of this value may be used, *i. e.*, 265 pounds per square inch. Hence, if b = breadth of belt and t = thickness, then $T_1 = btf$. (5)

Now since

$$T_2 = \frac{T_1}{\varepsilon^{\Phi\alpha}}$$

we have

$$P = T_1 - T_2 = btf - \frac{btf}{\varepsilon^{\Phi\alpha}}; \tag{6}$$

therefore

$$b\left(1 - \frac{1}{\varepsilon^{\Phi\alpha}}\right) = \frac{H\,P \times 33000}{Vtf}, \text{ or}$$

$$b\left(1 - \frac{1}{\text{anti-log } 0.4343\ \Phi\alpha}\right) = \frac{H\,P \times 33000}{Vtf} \tag{7}$$

Substituting the values of Φ and f, assuming $\alpha = \pi$, that is the arc of contact in degrees=180°, and noting that the number corresponding to the logarithm $0.4343\ \Phi\alpha$ is 2.3, we have

$$b = \frac{33000 \times H\,P}{\left(1 - \frac{1}{2.3}\right) 350\, tV} = \frac{166\, H\,P}{tV} \tag{8}$$

In average practice t=0.20 for single belting, but varies from 0.16 to 0. 25; double belting is supposed to be twice this thickness and varies in the same way. Substituting t=0.20 in (8) we obtain for sin-

gle belts with cemented joints, after rounding out the values of the numerical coefficient:

$$b = 800 \times \frac{H\,P}{V} \qquad (9)$$

and for single laced belts

$$b = 1050 \times \frac{H\,P}{V} \qquad (10)$$

Calling this coefficient C we obtain the general formula:

$$b = C\,\frac{H\,P}{V} \qquad (11)$$

in which C has the following values:

TABLE I.

VALUES OF $C = \frac{Vb}{H\,P}$

	Cement joint.	Laced joint.
Single belt	800	1050
Double belt	$\frac{800}{2}$	$\frac{1050}{2}$
Triple belt	$\frac{800}{3}$	$\frac{1050}{3}$

By using the Towne and Briggs coefficient of friction, viz., $\Phi = 0.42$, we obtain 650 and 850, respectively, for the values of C in (9) and (10)—a difference of nearly 20 per cent. under the conditions assumed. With a "mellow," supple belt and considerable slip, these values may give very good results as far as transmitting the power is concerned, but we prefer to use the larger values on account of the greater durability of the belt and consequent freedom from annoyance in stoppage and repairs which, as previously pointed out, should be an important factor in determining its width.

For belts of double and triple thickness, unless large pulleys are used, there is a loss both in bending the belt around the pulley, and in an actual reduction of the effective arc of contact. When the diameter of pully is less than 100 times the thickness of belt some allowance should be made for this loss. (Reuleaux.)

The amount of increase should be in some ratio, probably inversely proportional to the diameter of the smaller pulley, and to the square of the belt thickness. It is often customary to use $1 \div 0.7$ as a multiplier for all double belts irrespective of pulley diameter, but while this may be satisfactory in every case it is hardly necessary except for pulleys less than eight or nine inches in diameter.

For pulleys about 12 inches diameter $1 \div 0.8$ may be used; and for those approximating 20 inches, $1 \div 0.9$.

In the same way for triple belts running over pulleys about 18 inches diameter the width of belt should be increased in the ratio

$1 \div 0.7$; for pulleys about 26 inches diameter $1 \div 0.8$ may be used; and for those about 42 inches diameter, $1 \div 0.9$.

Calling this multiplier, C', we have the values given in the following table:

TABLE II.

VALUES OF C'=MULTIPLIER WHEN DOUBLE OR TRIPLE BELTS ARE USED WITH SMALL PULLEYS.

For double belts when diam. of pulley =	Or triple belts when dia. of pulley =	Value of coefficient C'
8 inches	18 inches	$1 \div 0.7 = 1.40$
12 inches	26 inches	$1 \div 0.8 = 1.25$
20 inches	42 inches	$1 \div 0.9 = 1.10$

Since Table I. was determined with an assumed arc of contact of 180° the values of the constant C should be multiplied by another coefficient when the least arc of contact on either pulley differs materially from 180°. This coefficient C", has been derived from equation (3) for different angles of contact from 120° to 240° and is given in the following table:

TABLE III.

VALUES OF C" FOR ARCS OF CONTACT.

Value of angle.		Value of coefficient C"
In degrees	In circ. measure	
120°	2.09	1.33
130	2.26	1.27
140	2.45	1.21
150	2.62	1.15
160	2.79	1.10
170	2.96	1.05
180	**3.14**	**1.00**
190	3.32	.95
200	3.49	.91
210	3.66	.87
220	3.84	.83
230	4.02	.79
240	4.18	.75

If the belt can be arranged so that the tight side will be on the bottom of the pulleys the arc of contact will be increased, since the slack side will thus embrace a greater portion of the upper surface of the pulleys, whereas if the slack side be on the bottom the arc of contact will be decreased when the belt is in operation.

At high speeds this is not as noticeable, since the centrifugal force tends to lift the belt away fom the surface of the pulley. In all cases, however, it is desirable to so arrange it where practicable.

Thus far we have neglected the effect of the centrifugal force, F_0, set up in the belt, but for speeds over 2,500 feet per minute its influ-

ence is appreciable and should be considered. Probably the simplest way to effect this in determining the width of belt is to diminish the allowable tension, f, per square inch of section, subtracting F_0 from f (since T_1 must otherwise be increased by this force); that is, the effective tension per square inch section is $f—F_0$. Since we have used f in determining the values of C it is evident that these values should be multiplied by a factor k_0 which is greater than f in the ratio:

$$\frac{f}{f-F_0}$$

Since the weight of a unit element of belt is constant, F_0 will be constant for a given speed; but as f=350 in the case of cemented belts and only 265 for laced, we shall have two sets of values of k_0, as shown in the accompanying table which has been calculated from

$$k_0 = \frac{f}{f-F_0} = \frac{f}{f-.41\,\frac{V^2}{g \times 3600}} \qquad (12)$$

TABLE IV.

VALUES OF COEFFICIENT k_0=MULTIPLIER WHEN CENTRIFUGAL FORCE IS CONSIDERED.

Velocity in feet per minute	Cemented belt	Laced belt
2,500	1.06	1.10
3,000	1.10	1.14
3,500	1.14	1.20
4,000	1.19	1.27
4,500	1.26	1.37
5,000	1.34	1.50
5,500	1.44	1.65
6,000	1.58	1.87

Multiplying these various coefficients together, we obtain the width of the belt:

$$b = C\,C'\,C''\,k_0 \times \frac{H\,P}{V} \qquad (13)$$

From this formula and the preceding tables a satisfactory width of belt can be obtained for any given case if the data are known.

For example, let it be required to find width of double belt to transmit 175 horse power at 3,180 feet per minute, pulleys 90 and 60 inches diameter. As cemented joints should be used we shall have:

$$C = \frac{800}{2} \qquad \text{(Table I)}$$

With the diameters of pulleys used it is probable that C″=1.05 (Table III.), and k_0=1.11 (Table IV.), hence

$$b = C\,C''\,k_0\,\frac{H\,P}{V} = \frac{800}{2} \times 1.05 \times 1.11 \times \frac{175}{3,180} = 24''$$

A belt 19½ inches in width was used.

An electric motor running at 1,600 revolutions per minute transmits an average load of 12 horse power through a single belt cement spliced; motor pulley, 7½ inches diameter; driven pulley, 48 inches diameter. Under these conditions the arc of contact (a^0) is about 140°, and V=2,950; hence

$$b = 800 \times 1.4 \times 1.2 \times 1.10 \times \frac{12}{2,950} = 6''.$$

A single belt (with cemented splice) six inches wide is in use. This belt occasionally transmits 15 horse power for several hours at a time.

The horse power which can be transmitted by a belt of given width may be obtained in the same way by transposition of formula; that is,

$$H\,P = \frac{V\,b}{C\,C'\,C''\,k_0}$$

For example, suppose, it be required to determine how much average horse power a 20-inch double belt (cement joint) will transmit when running at a velocity of 3,800 feet per minute, considering durability of belt; the smaller pulley is 16 inches diameter and the arc of contact about 155°. Here C=800÷2; C′=1.1; C″=1.12 and k_0=1.17, hence

$$\frac{3800 \times 20}{400 \times 1.1 \times 1.12 \times 1.17} = 135 \text{ H P.}$$

Fig. 2, obtained from the preceding formulæ, shows graphically the horse power transmitted by single and double belts one inch in width for both cemented and laced joints, under varying conditions.

It will be noticed that speed of belt, arc of contact and size of pulley for double belt are all taken into account, and one is enabled to obtain the power transmitted in a very simple manner. The diagram also shows that for laced belts the maximum horse power is obtained at a speed of about 5,400 feet per minute; for cement spliced belts the maximum is obtained at about 6,300 feet per minute, and any increase of speed above these values diminishes the power transmitted, assuming that the allowable belt tension remains the same—as it should.

To use the diagram let it be required to determine the width of double (laced) belt to transmit 30 horse power at 4,100 feet per minute over a 12-inch pulley having an arc of contact of 155°. Beginning at *O* we follow along the base line of velocities to *A* at 4,100 feet, then vertically upward in the direction of the arrow until it strikes the horse power curve for double laced belts at *B*. The horse power transmitted with an arc of contact of 180° and large pulleys would be about 6.3, as shown on diagram, but since the arc of contact is only 155° we project *B* across to the center line, obtaining point *C;* now follow parallel to the arc of contact curve, as shown, until point *D* is obtained on the vertical which passes through 155° at the top of the diagram. For large pulleys, say over 30 inches diameter, the horse power transmitted under these conditions would now be 5.7 horse power as shown at *E*, but we

have in this case a small pulley 12 inches in diameter, hence passing from D to the left until we strike the diagonal representing 12-inch pulleys we obtain point F, and the horse power may now be read on a scale at top of diagram corresponding to point G, viz., 4.4 horse power. Since 30 horse power is required to be transmitted, the belt will be $\frac{30}{4.4}$ or 7 inches wide.

CHEMISTRY BUILDING, UNIVERSITY OF MINNESOTA.

From the "University Souvenir" by courtesy of H. W. Wilson.

ELECTRIC TRACTION FOR HEAVY RAILWAY SERVICE.

BY EDWARD P. BURCH, CONSULTING ENGINEER, MINNEAPOLIS, E. E., '92.

It is the purpose of this paper to show the present status of electric-railway engineering and to point out some definite reasons why electric motive power will supplant the steam locomotive for heavy railway service.

PART I.

It will first be advantageous to review the development of electric traction toward heavy railway service. History relates that twenty years ago Edison built and ran small freight and passenger electric locomotives at Menlo Park. Five years later we find Van Depoele experimenting with the electric locomotive at Toronto and on the First Avenue steam line at Minneapolis. In 1887 Sprague, at Richmond, Va., installed the first successful street railway system. In 1890 many of the street railroads in the United States were replacing their horse, cable and steam dummy power with electric power. In 1892 we find many short suburban lines. The 40-ft. 15-ton car with the 25-h. p. motor on each truck, running at twenty-five miles per hour, was common. Grades up to 10 per cent were mounted.

While a splendid development was made by the street railways, we find greater progress in heavier work. The Intramural Railroad at the World's Fair in 1893 was followed by the adoption of electric power on the heavy elevated trains at Chicago and elsewhere—electric motors on each truck often displacing the compound steam locomotive, and with remarkable increase in capacity and speed, in traffic and net income.

Having passed the experimental stage, outgrown prejudice and a reputation for financial instability, we find electric power being utilized on long interurban and cross-country roads. Short interurbans were built first near Boston, Cleveland, Minneapolis and St. Paul, Buffalo and Niagara Falls. There is now an electric railroad through Indiana, ninety miles long. In the same state a 171-mile road and several 100-mile roads have been started. Dayton, Ohio, Detroit, Mich., have each an eighty-mile road. Toledo, Dayton and Detroit have each a fifty-mile road. There are over thirty-five cross-country electric railways (not street railway systems) each of which is over twenty-five miles long. Those now being built, extended or projected for this season's construction are legion.

The characteristics of the best recently built long electric railways are: A private right of way, ballasted roadbed, easy curves and

grades, 75-lb. T-rails, long, comfortable, clean and splendidly lighted double-truck cars; one to three car trains; four 75-h. p. motors per car, rapid acceleration, a maximum speed of fifty miles per hour, swift stops, Westinghouse or other air brakes, air whistles, arc lamp headlights; trucks, axles, wheels, etc., following Master Car Builders' standards; telegraph, telephone and block signal systems. These passenger roads seldom have freight traffic, although heavy express and mail services are systematized. They are operated under the same rules as govern steam roads. Many of them are managed by our broad-gaged experienced steam railway men. The service is reliable and frequent, and fares are cheap. These are the inducements to travel. The greatly increased density of traffic enables the practice of increased economy in the use of the road bed and equipment, a fundamental principle to be observed in successful railway management.

The first application of electric locomotive cars to steam road service was made in 1895 on the Nastasket branch of the N. Y., N. H. & H. R. R. Two and three coaches were hauled at a maximum speed of 40 m. p. h. Both the trolley and third-rail contact systems were used. Later installations by this company embody the use of four 175-h. p. geared motors under each 50-ft. standard passenger coach. Seventy miles of track on divisions near Boston, Hartford, New Britain and Berlin are now in service. The electric line from Hartford to Bristol, which has very heavy passenger traffic, yet in few trains, is now being extended to Waterbury, Conn. The N. Y., N. H. & H. R. R. has found electric traction on trunk railways economical and entirely successful. This company, the pioneer in electric traction as applied to steam roads, has published the results of most exhaustive tests made on its equipments under normal operation with very high tests made under severe conditions; also complete comparative statements showing the economy of operation.

In 1896 the Pennsylvania R. R. introduced electric traction on its Mount Holly branch—some eight miles of double track. The Boston & Maine R. R., which has operated an electric road at Portsmouth, N. H., for two years with good results, is reported to have purchased material for a heavy thirty-mile road from Concord to Nashua.

Railway engineers now recognize the fact that electric traction is adequately furnishing the service now being done by steam locomotives in heavy passenger service. At the September, 1900, Paris International Railway Congress, many engineering reasons for this fact were presented to the congress. The reports also showed that main lines of steam railroads, where electricity had been substituted, are operated under the same rules, with the same weight of trains, the existing railway train schedule, without loss of time and with financial success.

In 1895 the Baltimore & Ohio R. R. put in service three heavy electric locomotives for hauling standard passenger and freight trains

BUFFALO &
LOCKPORT RAILWAY
2
9244

through the B. & O. tunnel under Baltimore. Each locomotive weighs 194,000 lbs., all on the drivers. They are rated 1,500 h. p. each. A draw bar pull of 60,000 lbs. is easily obtained and trains weighing 1,900 tons have been hauled up the 42-ft. grade at twelve miles per hour. Ordinarily, each locomotive hauls 1,400 tons on the level at fifteen miles per hour. Faster work can be done with these locomotives than with steam locomotives. The management states that they thus save in the track required. They are handier, accelerate rapidly, yet are much less liable to break a train in two in starting. The advisability of extending the use of the electric locomotive on an eighty-mile division of the road is now under consideration.

In 1896 two 660-h. p. electric locomotives having 136,000 lbs on the drivers, were installed on the Buffalo & Lockport Ry. for switching purposes over the tracks of the Erie R. R. Twenty loaded cars are commonly hauled. (See half tone.)

Since these early installations, hundreds of heavy electric switching locomotives have been purchased for use in railroad yards, terminal railways, belt lines, at factories, steel mills, etc. Two hundred electric mining locomotives have been sold by one manufacturing company within two years. Great advance may be expected from the consolidation of interests of one of the steam locomotive builders with a leading electric manufacturing company.

It is thus evident that conservative railroad managers, who are convinced of the advantages of electric traction as a matter of commercial economy, will now have plenty of precedent for their guidance.

The heavier electric roads and those hauling freight on a private right of way have replaced the heavy trolley with the less expensive and much safer third-rail system, the latter being superior for heavy traction. Examples are noted on the B. & O., the N. Y., N. H. & H. R. R., the Albany & Hudson railway, on elevated roads, etc. The third rail, located at the side of the track rails, gives little trouble. If necessary, it is easily protected. At grade crossings where the third rail is removed, the rear shoe of the 50 or 60-foot coaches holds the connection until the front shoe regains it. In this case the circuit is run underground or on poles at each crossing. The overhead trolley, however, has advantages in switching yards, in which service we find a trolley pole (one which does not need turning) above the locomotive or car, and the third-rail contact shoes at the lower side.

A few years ago heavy electric traction received a set-back because of the great loss of power in transmitting the electrical energy. The standard low pressure then used, 600 volts direct current, was not economical in heavy railroad service where the distribution in a given direction from a central station exceeded ten miles. However, this difficulty was removed by using a different transmission system. Since electricity can be transmitted with a very small loss at higher voltages, the longer roads found it necessary and economical to gener-

ate the power at one large station and transmit it at high voltages as alternating current, to from three to eight sub-stations or local distributing points. Examples of this are noted on the Union Traction Co.'s road through Indiana, the Toledo, Fremont & Norwalk, the Rapid Transit Railway Co.'s system from Detroit, etc., where 16,000 volts is the distributing potential. The Albany & Hudson River Railway and Power Co., the Buffalo & Niagara Falls Electric Ry., the Southwestern Missouri Electric Ry., and many other roads, use a transmission pressure of 11,000 volts. As described in full in my April, 1900, paper before the Club, 8,000 h. p. are transmitted from the Pillsbury dam in Minneapolis to the Twin Cities at from 3,500 to 12,000 volts' pressure by lead-covered transmission cables, part of this power being used on three heavy interurban roads. The finest example of this practice (now used by over fifty electric railway systems in the United States) is in connection with the Metropolitan Railway Co.'s 70,000-h. p. station in New York City, where power at 6,600 volts pressure is distributed to six sub-stations. Improved types of lightning arresters have been developed which make these high voltages safe and the service most reliable. Eighty-mile transmissions are becoming numerous.

In Europe the development of electric traction for heavy railroad service has been most substantial. The City & South London railway was the first heavy electric railway, and has hauled three coach trains by electric locomotives since 1890. The largest equipment of locomotives ever made was for the Central London Underground Ry. Forty 48-ton locomotives, each equipped with 800-h. p. in gearless motors, with a speed of forty miles per hour, are used. Germany leads, however, due to excellent experimental work on heavy trunk lines by the leading electric manufacturing companies and also to substantial aid from the government. Very high voltages have been successfully used on locomotives when speeded up to eighty miles per hour. Remarkable savings have been made by the use of the electric locomotive in freight switching yards. The Dusseldorf-Krefeld Electric Railway and the Standstad-Engelberg Railway are fine examples where freight and passenger locomotives are used on short main lines. In Switzerland the leading electric railway is the Burgdorf and Thun trunk line, carrying very heavy freight and passenger traffic. Experimental data, complete drawings and elaborate tests of the three-phase motor equipments used have been published by Carus-Wilson. Italy is not behind. Successful lines of importance are the Lugano light tramway, in operation since 1890; the Lecco Ry., sixty-eight miles long, and the Varese sixty-six-mile road with its heavy service in Northern Italy. The Italian government has approved electric railway projects of great magnitude, and work is now in progress on important and very long trunk lines, which will be operated for high-speed passenger and heavy freight traffic.

The common features of these important heavy electric railways on the continent are: No connection with street railway systems, magnificent road beds over a private right of way, heavy cars in three and four-car trains and with the motive power on the locomotive. Heavy grades are mounted—3 to 5 per cent. Water power is used in almost all cases. The transmissions are at about 15,000 volts and the motors are quite universally of a three-phase induction type operating under a pressure of 750 volts—although 3,000 volts are used on the Lecco and other roads.

Recently some of these motors have been manufactured in the United States. The European engineers have attained a high degree of perfection in this development. This is due, in large measure, to the use of alternating current motors. These polyphase motors have advantages over the direct-current types perfected in this country. A matter of superior engineering advantage is that with all loads and grades the speed is practically uniform. On descending grades power is returned to the station. The induction motor is also much simpler and will stand more abuse. These motors are preferable on all long electric railroads. The matter of series-parallel control and of standardization is now well developed and objectionable features are being removed. The polyphase system does not require moving machinery and labor at sub-stations.

The engineering departments of our American manufacturing concerns are fully cognizant of the development of the polyphase system of electric traction by our European fellows, and are now devoting their energies to the polyphase-traction problems because of the demand which has arisen for equipment of this nature.

PART II.

Electric traction applied to steam railroads will or should mean very few radical changes. Consider the adoption of electric power on some railroad having, say ten or more trains in each direction daily, for example, on any road radiating from the Twin Cities to Fargo, to Duluth, the Soo, to Chicago or to Omaha. The water tanks, the coal depots and their usual attendants, machinery, trestle work and buildings, will be consolidated in a few advantageously located central power stations. The locomotive tender, with its coal and water load, its repairs and depreciation, will be absent, and power will not be necessary for its propulsion. All the locomotive boilers and engine cylinders, the piping and accessories will be exchanged for a few large and economical steam producers and prime movers. Fewer locomotives will be necessary, as each will be capable of higher speed and greater annual mileage, and there will also be a smaller proportion in the shops. Some of the locomotive firemen may be utilized in the power stations. The steam locomotive is short-lived and is either rebuilt, worn out or a drag on the service after ten years' work. The mechan-

ical superintendent need not worry about a larger scrap pile. Ordinarily the steam locomotives will be used up, on divisions not equipped for electric traction, or sold. The heavy electric locomotive will simply be substituted for its steam rival. The balanced working parts, general simplicity and ease of control will commend it. In addition to the substitution noted above, which will save an immense amount in depreciation, heavy additional investment will be necessary for metalic conductors to transmit the electrical energy, transformers (located at ticket stations) and working conductors for the electric motors.

An electric locomotive, or a train equipped with electric motors, has its starting torque or effort evenly distributed around the driving wheels—i. e., it does not vary due to the angularity of a connecting rod and a varying piston pressure. For these reasons the common electric locomotive has over 35 per cent greater tractive force than the steam locomotive with equal weights on the drivers. In a comparative test on B. & O. locomotives on a dry rail, without sand, a tractive co-efficient of 30.8 per cent was found with the electric locomotive, while a tractive co-efficient or maximum draw-bar pull of 20.6 per cent of the weight on the drivers was found for the steam locomotives. (The co-efficient of friction is not different in the two cases.) It has also been shown that, owing to the steady torque of electric motors, at least 20 per cent of the weight on the drivers is available for starting. Again, in the design of electric locomotives for heavy freight service, all the weight is placed on the drivers, utilizing every pound for traction. Heavy steam locomotives in common freight service lose by having from 12 to 20 per cent of their weight on the truck wheels. We may also note that for passenger service, the steam locomotive with its heavy boiler has a very much heavier dead load than is needed for traction. On the Empire State Express, the locomotive and tender amount to 37 per cent of the entire train weight; the electric locomotive would save 25 per cent of the entire train weight and 25 per cent of the power. We often see a sixty-ton steam locomotive hauling a forty-ton tender and two or three forty-ton coaches. The electric locomotive thus weighs at least 50 per cent less than the steam locomotive and coal tender, especially so for switching and passenger service. Electric traction for railway service also makes possible a most rapid acceleration. B. &. O. electric locomotives hauling trains weighing 985 tons, easily accelerate to a speed of twelve m. p. h. in one minute. In the well-known Sprague multiple unit system, in use on American elevated railroads and elsewhere, each coach is commonly equipped with two motors on each truck. (The train, with from three to seven coaches, is operated by a small master controller located at either end of any coach.) This system is economical and quite necessary where the service consists of many stops. Rapid acceleration is possible because the weight of the entire coach is distributed on driving wheels.

From an operating standpoint, electric traction will be found economical when substituted for steam locomotives on some steam roads. The Inter-State Commerce Commission in its statistics of railways in the United States for 1899, reports on the operating expenses of steam railways as follows:

	Per Cent.
Item 1—For repairs of roadway	10.72
Item 12—For repairs and renewals of locomotives	6.20
Item 20—For water supply of locomotives	.62
Item 21—For engine and roundhouse men	9.69
Item 22—For fuel for locomotives	9.47

These five items amount to 36.7 per cent of the total operating expenses of railroads.

Take up the foregoing items. 1. Repairs of Roadway: As is well known, it is the steam locomotive and not the train that causes heavy repairs to roadways. The heavy dead weight on the driving wheels cannot be distributed, but is intensified by a short, rigid wheel base; damage results. Electric traction at once presents advantages. First, the dead weight on the drivers of the perfectly balanced electric locomotive is not over 75 per cent of its steam rival. As previously shown, this is due to the uniform and rotary application of the power. All the weight can be carried on the drivers. In freight locomotives every pound is needed for traction. Second, in electric passenger locomotives we eliminate the dead weight of the boilers, etc., which is greatly in excess of the requirement for traction. Third, the absence of the tender and its coal and water saves in the weight as well as in the capacity of the locomotive. Fourth, a very important consideration is the absence of the hammer blow of the drivers on the rail. This hammer blow subjects the track to a series of shocks and violent vibrations, from the effect of which the ties become loose in the ballast. (As the two cranks are set 90 degrees apart, the unbalanced horizontal weight tends to swing the steam locomotive to one side and then to the other, nosing so-called. Spikes loosen and rails spread.) Many other practical demonstrations have been made of this unavoidable phenomenon. "Heavy rails have been kinked and bridges have been shaken to their fall, all under the action of heavily balanced drivers revolving at high speeds." Fifth, in the ordinary design of the electric locomotive, the weight of the motors and frames on the driving wheels is distributed over a long wheel base and on at least two trucks. In the multiple unit system where the motors are distributed to each truck of each passenger coach the repairs to roadway are even less than with an electric locomotive at the head of the train.

For these reasons electric traction makes a remarkable saving in the labor and material needed for the repairs and renewals of road-bed, of bridges, docks and wharves, trestle work, embankments, rails, ties, switches, frogs, curves and other special work. The damage due to

soft spots in soggy track after heavy rains, and that caused by spreading of rails, is also diminished.

Item 12: Repairs and renewals of steam locomotives are heavier than they are on electric locomotives, simply because of the greater pounding, vibration, racking of machinery and the wear of heavy frames, boilers, cylinders, running gear, drive wheel tires, etc. The fact is also clear that in design the steaming qualities, capacity and speed are of greater importance than low repairs and renewals. The life of steam locomotives is but ten years. The same capacity in stationary boilers and Corliss engines does not cost 10 per cent as much for repairs. At the end of ten years' service the modern power station does not show material depreciation. Repairs of the perfectly balanced electric locomotives are a small item, due largely to the absence of reciprocating parts, multiplicity of parts and unnecessary dead weight. After studying the details making up steam locomotive repairs as given by an authority, Mr. Arthur Wellington, one must conclude that from the very nature of things 60 to 75 per cent of the cost of these repairs disappear with the use of electric locomotives.

Item 20: Water supply for steam locomotives: This item, also repairs, renewals and supplies for the coal tender, the coal elevating, and pumping machinery, power and labor at supply stations, disappear in electric traction.

Item 21—Engine and roundhouse men: This is an item where a great saving can be made. First, it is true that at present two men are generally needed on an electric locomotive for high speed passenger and for heavy freight service—for safety and reliability, if for no other reason. It is equally true that for construction work and for switching, which work constitutes over 25 per cent of all locomotive service, and for all branch lines hauling one or two combination coaches, one engineer would in almost all cases be sufficient. The greater simplicity of the electric motor would enable the train crew, near by, to be of service in case of an emergency. One of four motors being crippled, the remaining three would always serve all purposes until the end of the division was reached. Second, it is believed that when electric traction is introduced on a larger scale, the rate of wages paid can be materially reduced. This belief applies particularly to freight service. If it is true, and our steam railway men think it is, we have here another important saving. Third, time is saved by more rapid acceleration, faster speed, swifter stops, and by shortening the delays at water stations, etc. Fourth, in the roundhouse and shops, the same cleaning and inspection are needed by the electric locomotive, but fewer men are required since there are fewer parts requiring inspection, renewal and repairs—a large part of the apparatus, the boilers, cylinders, etc., being centralized at the power station.

Item 22—Fuel for Locomotives: This averages 9.47 per cent of all operating expenses. The steam locomotive does not use fuel eco-

nomically. The boiler produces steam with some economy at high pressure. An actual evaporation of 6.0 pounds of water per pound of coal, or 6.5 from and at 212 degrees, with good coal on heavy freight service, has recently been shown. But the steam is used at great disadvantage. In switching service it is very largely wasted. In passenger service, using about 2,300 pounds of coal per 10,000 ton-miles, or 3.60 pounds of coal per average indicated h. p. h., the cylinders use steam with some economy when the cut-off is from 25 to 30 per cent of full stroke. Ordinarily the engine cannot be economically loaded. If the load is light or if the engineer is using steam at two-thirds stroke, or "down in the corner," the waste is abnormal, not only in the cylinders but in the boiler. Professor Goss cites a test on the C., C., C. & St. L., where the boiler decreased in efficiency 25 per cent when the number of pounds of coal burned, per square foot of grate service per hour, was increased from five pounds to ten pounds. In passenger service no attempt toward economy of fuel is practiced, economy being sacrificed to good service; for a broad railway manager believes in sacrificing coal whenever the regularity and punctuality of the train service can be improved.

In freight service the economy is relatively lower (not higher) per h. p. h. The modern freight locomotive requires about 1,300 pounds of coal per 10,000 ton-miles, or 5.0 pounds of coal per i. h. p. h. Here is where the greatest saving can be made. Modern steam plants in electric railway service show 10 pounds of water per pound of coal and 1.75 pounds of coal per i. h. p. h.

A recent paper before the Club, "The Traveling Engineer," shows the difficulty of making the fireman and engineer use good judgment in generating and using steam. Their minds and eyes should be ahead, on the track and signals. Economy of fuel should never be expected of them. It is a fact that the steam locomotive depends upon the skill of the men who handle it for its efficiency, while the electric locomotive does not.

Then in both the freight and passenger steam locomotive there are losses due to radiation of heat from the boiler, unlagged saddle castings, valves and cylinders. In the cylinder, the losses due to condensation and due to the high speed are large. The loss by direct leakage past the piston, with the high pressure used, is found to be heavy. The cylinder valve is designed with other consideration than economy in view. Wire-drawing is noted, and condensation where the live steam ports are also used for the exhaust steam. The feed water on steam locomotives is seldom heated to 100° F. The possible saving here amounts to 10 per cent. A saving of 40 per cent of the steam would be possible if the simple steam locomotives could run compound condensing, a saving of 23 per cent if compound locomotives could run condensing. The compound locomotive, where used, saves but 15 to 20 per cent of the steam on heavy service and 5 to 15 per cent

in light and faster service. The friction of the heavy reciprocating piston, piston rod, crosshead and running gear is found to be abnormally high, commonly amounting to over 500 lb. draw-bar pull. Experiments by Goss show that from 72 to 94 per cent of the indicated power of the cylinder can be accounted for by the speed and dynamometer pull at the engine draw bar. The loss noted at 10 miles per hour averaged 6 per cent; at 55 miles per hour, 23 per cent. The dynamometer car on the Pennsylvania road shows that a much greater loss (45 per cent) is common. The loss due to the friction of gearless electric motors is materially less, especially so at high speeds.

In the matter of capacity the steam locomotive is limited. Mr. Angus Sinclair, the able editor of Locomotive Engineering, writes: "The gage, 4 ft. 8½ in., is too narrow for admitting a properly designed boiler upon a large locomotive. Many steam locomotives have reached the limit of their capacity because the limited gage prevents the boiler being made larger." The gage does not limit the design and the capacity of the motors in electric locomotives. The steam locomotive has its source of power upon its back. The electric locomotive has the entire power station behind it. In steam locomotives, the moving parts reciprocate and thus also the speed of passenger trains is limited. The moving parts of a motor rotate. Likewise, the backbone of railroad business, the freight traffic, now calls for heavier trains and much faster schedules. Railway managers demand this. Expenses are per train-mile, and the revenue per ton-mile. How is this demand to be met if the limit has already been reached in the capacity of steam locomotives?

In the matter of the economy of fuel there is, then, no comparison between ordinary simple or compound steam locomotives and the following: A large central power station, mechanical stokers under well cleaned boilers supplying steam to an economically loaded, compound condensing Corliss engine, or to a steam turbine. The larger unit is more economical than several small ones on steam locomotives. In central stations cheaper grades of fuel may be used—slack, hard coal screenings, or lignite—which are burned at a great disadvantage under a steam locomotive boiler. The writer recently conducted a series of commercial fuel tests at an electric railway power station, which showed a large saving per horse power-hour output, by using cheap Iowa slack in place of the best Illinois lump. The daily records of one of our roads shows that it takes from 25 to 30 per cent more coal per 10,000 ton miles in Dakota and Minnesota, where the locomotives use alkali water which deposits heavy scale in the boiler, than it does on Wisconsin divisions, where the water is good, other conditions being comparable. The central power station using surface condensers or a water softening device would prevent this scale, save in fuel, repairs to leaky flues, boiler washing and scraping.

Summarizing, we may list the approximate savings:

	Per Cent.
By using cheap fuels	20 to 10
By heating feed water to 212 degrees	10
In locomotive boiler economy	33 to 20
Due to less scale in boilers	20 to 0
In cylinder radiation and condensations	10 to 5
By using larger prime movers	15 to 5
In leakage past the piston	5
By running condensing	40 to 25
In friction of piston, crosshead, rod and crank pin	5
Decrease in train weight (locomotive and tender)	25 to 10
Total saving of central station over the steam locomotive	65

Or, the relative economy of fuel by the central station and steam locomotive, 100 to 35. This is a most conservative estimate.

The additional power generated by the sationary engine is:

	Per Cent.
For electric generator losses, average	4
For high tension transmission losses	5 to 8
For transformer losses	4
For low tension distribution losses	5
For electric motor and controller losses	10
Total additional power required (product)	35
Total net relative economy of power required at the draw-bar, 100 to 35 x 1.35, or	47
Total net saving in fuel, reduced to draw-bar of locomotive.	53

This saving of over half the coal bill on existing steam roads, made possible by the introduction of electric traction, means a net saving of 5 per cent of the total operating expenses of railways.

Generally speaking, it would be still more advisable to utilize the latent water power so abundant in our Northwestern states, where coal is either expensive or poor. Water power when developed without excessive capital expenditure is the cheapest known source of mechanical or electrical energy. A water power station is ordinarily very reliable. The care of the water supply and the turbines is infinitely less than that with coal supply, boilers, piping and engines—saving also in interest, depreciation, and especially in labor for operation and repair. A local 10,000-h. p. plant and transmission cables, with a daily maximum output of over 7,000-h. p., requires but eight men per 24-hour run.

The principal last-century arguments used against the use of electric power on heavy railroads are headed:

Inability to do the heavy work required.

Unreliability, especially during snowstorms, lightning storms, etc.

Danger of the third rails and trolleys, high voltages, etc.

Heavy investment for additional equipment.

These arguments, with the exception of the last, have been touched upon in the paper. Heavy investments are only warranted when resultant economy can be clearly shown. No one seriously considers the question of the lack of good judgment when fuel and labor saving devices such as condensers, large units, stokers, heaters, etc., are installed in our modern power stations. These are now as simple a proposition as investing money for storm windows on our houses. Some subsequent paper may show the equipment required for heavy railway service on trunk lines, the general plans, amount and distribution of power, specifications, cost and accompanying operating expenses.

In the application of electric traction to heavy railway service, the steam railway engineer and the electric railway engineer must work together. Their first work is to ascertain the facts as they exist—to ascertain the actual power required for all classes of service, switching, freight and passenger. The facts regarding average and maximum power require the best judgment. Each possible saving must be detailed, as outlined; in repairs of roadway, repairs and renewals and supplies for locomotives, in wages of engineers, firemen and helpers, and in the shops, in fuel and in many other items which at once suggest themselves. Contrariwise there will be the interest, depreciation and maintenance of additional equipment, central power stations with either steam prime movers and boilers (or a dam and turbine), electric generators, transmission lines, transformers and alternating current distribution.

Electric traction is clearly an important development in railway engineering, nothing radical being proposed. Its adoption is never warranted except on a basis of increased economy of operation. The supercession of the steam locomotive by the electric locomotive is primarily a question of profit and loss, and here the proposition stands in favorable light for commercial consideration.

The foregoing article was read by Mr. Burch before the Northwest Railroad Club January 16 at Minneapolis. The article excited much comment at the time and by courtesy of the Club is published here for the benefit of the members of the "SOCIETY" who have been unable to procure it in any other form.

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UNIVERSITY OF MINNESOTA

MAY, 1902

UTILIZATION OF NATURE'S ENERGIES.

By J. T. Fanning, C. E.

Useful Works:—The relations of energy to the useful and successful works of practicing engineers are impressively reflected in recent census statistics of power used in commerce, manufactures, transportations and in mining.

The rate of potential energies, by aid of which the products of all these varied enterprises have become real, is stated only in millions of horse powers and it has been the province of engineers to design and install the mechanisms by which these vast energies are now made subservient and useful.

It is proposed to consider at this time, in a popular rather than technical manner, the progress in methods of conserving, applying and broadening the field of such utilizations of nature's energies.

If the engineer dams up the flowing stream and diverts the waters it is that he may guide their potential energy into a power house and to make them work. If he builds a turbine water wheel of high efficiency it is that it may convert the potential energy of the flowing stream into rotative useful energy. If he builds a steam engine, strong in parts and well proportioned, it is that it may convert the tremendous energy generated in the boiler into mechanical work. If he builds a mill it is that the energies converted into useful forms by the turbine and the engine may drive the machines that will by their varied works produce useful articles of manufacture. If he builds a dynamo

it is that the energy which pervades our enveloping ether, like that of the lightning flash, may be gathered in the generator shaft and marshalled into useful work.

Early Applications of Energy:—Our Colonial Forefathers had but slight acquaintance with the energies of nature. Their education in mechanics was chiefly in setting the sails of windmills so that they would turn the mills and grind their corn.

The old tide mill in Boston, in 1631, was the conspicuous pioneer of American water powers and to this power were carried the grists from the colonial farm houses from many and many miles around. The old Slater spinning mill in Pawtucket was, after the close of the Revolution, the pioneer American cotton mill, driven by the falls of the Blackstone river, and to this mill went the early growths of American cotton to be made into yarn. When there was projected the pioneer American mill that was to attempt to both spin the cotton yarn and weave it into cloth, it sought the water power of the Charles river at Waltham in the year 1813. It proved a successful experiment and the era of American cotton manufacture was inaugurated.

Larger Energies Sought:—Then, in 1821, as a result of this experiment, capitalists of Massachusetts went back into the wilderness and investigated Pawtucket and Amoskeag Falls on the Merrimac river. Before the close of the decade of the 30's, the water powers at Lowell and Manchester and Lawrence, on the Merrimac, were developed and the citizens of the young American states first took rank as a manufacturing people.

So also the large water powers at Nashua, at Cohoes, at Holyoke, at Lewiston, in the New England states, and other water powers were sought out and in process of time the great water power of the Northwest at St. Anthony Falls, in 1856, was sought out and all were developed as mighty workers and made the nuclei of manufacturing centers.

These great powers have not been enumerated merely as historical matters of much interest but rather to illustrate facts that in the early inauguration of industries when great works were to be done, sources of great natural energy were sought out and utilized and the works of the community went where the energy was found.

Shaft Transmissions:—In utilizing these great sources of natural energy they were first converted into rotary motions and gathered in their shafts and transmitted to their works near at hand by their shafts.

These were at first hewn timber shafts with iron gudgeons and hoops and about these shafts were framed the great wooden water wheels. Cast iron shafts were at first used to distribute

the power. When turbine water wheels, in 1844, superceded the overshots then slowly revolving lines of hammered iron shafting distributed the power along the length of the mill. A few hundred horse powers was then the limit of capacity of the mill shafts.

Now finished steel shafts with rapid revolutions are far more efficient.

To illustrate the progress from then to now along this line of converting potential energy into rotary motion, reference is made to a set of steam engine units now nearly fully installed in which the respective steel shafts are tubular with 34 inches external diameter and are to handle 12,000 horse powers each.

Shaft transmissions have, however, been always limited in their reach to works near at hand, say within five or six hundred feet, and rarely one thousand feet. The work which they can directly accomplish must come within this limited area.

Belt Transmissions:—Pulleys and flat belts subdivide the unit energy given out by the shaft and have enlarged slightly its sphere of work and multiplied the number of machines the unit energy may operate.

Rope Transmissions:—The rope drive introduced a new element, for by its aid the energy at the source of its conservation may go out to do its work to a further but still limited distance, even beyond the adjacent hills. This is significant in the fact that here power goes to its work while in the important examples heretofore cited work has gone to the source of the power.

We may cite an example on the Chattahoochee river at Columbus, Georgia, in which the power house is adjacent to the forebay on the river shore and the cotton mill using the power is high up on the adjacent bluff. Here 1500 horse power of energy goes by a manilla rope drive from the turbines to work in the mill.

On the Missouri river, at Great Falls, Montana, there is at the smelter plant a more extensive manilla rope drive that has been ten years in operation driving the shafting of the miscellaneous machines used in the reduction of copper ores on a great scale.

One of the most successful of wire rope transmissions may be seen in this city where the wire rope takes power from the dam 10,000 feet to the several manufacturing plants on Nicollet Island.

Hydraulic Transmissions:—Hydraulic transmission of power by high pressure systems has had but moderate use in America but it illustrates another system of the transmission

of energy by which the field of work transmitted from a central station is greatly broadened.

The writer observed numerous examples of its use at the docks and railway stations in England and France where it is extensively used in handling freights.

Accumulators:—The ingenuity of Lord Armstrong who has for half a century been known as an expert mechanic gave a convenient device for the accumulation of high water pressures. He made a smooth metal plunger of about twenty inches diameter and twenty-five feet length and arranged it to move vertically in a metal cylindrical chamber through a stuffing box. On the top of the plunger were placed weights which in their aggregate weight were equal to 750 times the square inches in the horizontal sectional area of the plunger. Then when water was pumped into the chamber containing the plunger and its pressure slightly exceeded 750 pounds per square inch the plunger was supported by water pressure and moved upward as more water was pumped or descended as water was drawn out, and the water pressure remained at about 750 pounds per square inch.

This hydraulic apparatus is known as the accumulator. It serves admirably for the storage of power that is to be used intermittently as in the operation of cranes for lifting and handling weights in foundries and shops and for handling freights at railway stations, and for the movements of heavy swing bridges, or lock gates, and for punching and shearing metals. The pumps supplying the water to the accumulator work continuously until the plunger has reached its highest limit when the pumps are stopped automatically. The accumulator is then ready with its reserve power and the plunger descends as the work goes on and ascends as work slacks.

The crane so largely in use for such power was invented also by Lord Armstrong.

Frictions:—The efficiencies of such an hydraulic plant are modified by the character of the appliances used. From the water wheel or steam engine to the work there are the frictions of the pump, of the plunger, of the flow of water in the pipes and of the motor. The frictions of water flow in the pipes depend on velocities of flow and upon the lengths of pipes and are inversely as the diameters of the respective pipes. Cast iron pipes of six and seven and one-half inch diameter have been commonly used but larger seamless steel pipes may now be had in the market well adapted to sustain high pressures. The velocity of flow of water in the pipes is usually limited so that the friction loss will not exceed about 7 feet head or 3 pounds

per square inch in each 1,000 feet length of pipe between the accumulator and the work.

Velocities of flow per second and friction losses of head per 1,000 feet are substantially as follows:

6 inch pipe, 3.0 feet velocity, about 7. feet loss per 1000 ft. length.

8 inch pipe, 3.5 feet velocity, about 7. feet loss per 1000 ft. length.

10 inch pipe, 4.25 feet velocity, about 7. 5 feet loss per 1000 ft. length.

12 inch pipe, 4.67 feet velocity, about 7.25 feet loss per 1000 ft. length.

The efficiencies of such pressure plants usually are from 68 to 78 per cent, and of the transmission pipes 95 to 98 per cent, giving 65 to 76 per cent at entrance to the working motors. The motors are usually of the piston form with reciprocating motions and frequently have efficiencies as low as 40 to 60 per cent in which case the final efficiency of the whole plant may not exceed 30 to 45 per cent.

Limiting Capacities:—To compute the horse power capacity of such a pressure plant, we have,

$$\text{H. P.} = \frac{\text{Lbs. water per sec. x equivalent head in ft. x rate of efficiency.}}{550}$$

The capacities of such units of accumulators is not great as is illustrated by the following table:

Capacity for 750 lbs. pressure at 70 per cent efficiency.

6 inch pipe, 3.000 ft. veloc., 0.589 cu. ft. per sec., 80.74 H. P.
8 inch pipe, 3.500 ft. veloc., 1.221 cu. ft. per sec., 167.45 H. P.
10 inch pipe, 4.250 ft. veloc., 2.318 cu. ft. per sec., 317.76 H. P.
12 inch pipe, 4.667 ft. veloc., 3.665 cu. ft. per sec., 522.50 H. P.

In computing the thickness, t, of the pipes, it is common practice to add 100 pounds to the working pressure to cover water rams and then take a factor of safety equaling 5 for cast iron pipes and 4 for steel pipes and for standard metals to allow 18,000 lbs. per square inch as the tensile strength, S, of cast iron pipes and 60,000 lbs. per square inch as the tensile strength of steel pipes without a longitudinal joint.

The formula for thickness, t. of pipe, in inches, with diameter, d, in inches, is

$$t = \frac{(p + 100)\ .5d}{S} \times 5, \text{ for cast iron, and with factor 4 for steel.}$$

The thickness of 6 to 12 inch pipes is, for 750 lbs. pressure,

6 inch pipe, cast iron, 3/4 inch, steel, .170 inch.

8 inch pipe, cast iron, 15-16 inch, steel, .227 inch.

10 inch pipe, cast iron, 1 3-16 inch, steel, .284 inch.

12 inch pipe, cast iron, 1 ⅜ inch, steel, .340 inch.

Examples of Hydraulic Systems:—Referring for example to notes of an hydraulic high pressure plant in Glasgow, we find that plant to have had, in 1891, one double high pressure engine driving two pumps of 4-inch diameter and 19 ½ inch stroke and one compound condensing engine driving two pumps of 5-inch diameter and 19-inch stroke.

These engines with 70 pounds steam pressure were working the pumps against 700 pounds water pressure. The plunger of the accumulator was 20 inches in diameter and its vertical lift was 24 feet.

This hydraulic plant operates 4 twenty-ton and 3 two-ton cranes at the side of the dock and also 22 capstans for hauling and switching freight cars, a coal car dumper which lifts bodily a car loaded with coal and dumps the coal into the hold of a vessel and operates the lock gates and also a 200 foot swing bridge at the entrance of the dock.

Sometimes for lower pressure plants the water is pumped to a reservoir with 200 or 300 feet elevation and then the water is conveyed to pressure work by pipes, as when water motors are operated by public water supplies. The river Rhone as it passes through the City of Geneva in Switzerland presents an early and interesting example of hydraulic pressures produced by water power and piped to various works scattered about the City of Geneva. In our western mining regions we have numerous examples of high pressures from natural mountain streams, with pressures of 500 to 700 feet head, where hydraulic power from impulse water wheels are used for various mining works.

The most conspicuous example that may be cited of high pressure hydraulic power for general power distribution is that of the London Hydraulic Power Company. Their works, inaugurated in 1884, consist of three steam pumping and pressure stations having an aggregate power supplying capacity of 3800 horse power and their pressure water is delivered to consumers at a pressure of about 750 pounds per square inch. This pressure system was, in 1892, working about 1700 small machines that are widely distributed along their system of pipes.

Air Transmissions:—Compressed air has proven almost invaluable as a vehicle for storing and transmitting energy in many great engineering works.

It was one of the earliest processes in power evolution by which it was demonstrated that power might be sent to the work to be done, and that work need not necessarily go to the power. Soon after the middle of the last century air compression by ma-

chines received its first large practical development in America for the purpose of storing and transmitting power, at the Hoosac tunnel in Massachusetts. Hoosac mountain is a part of the ridge that separates the water sheds of the Connecticut and Hudson rivers. The Deerfield river flows southeasterly along the eastern base of the ridge to opposite Hoosac and then turns at right angles and flows easterly to the Connecticut river. The Hoosac river flows southerly along the western base of the ridge to opposite Hoosac and then turns at right angles and flows westerly to the Hudson river.

During the American canal era, 1800 to 1840, a canal was projected from Boston to Albany. Hoosac mountain, five miles in breadth at its base, was found the great barrier to such a desired work, but the surveyors, with remarkable boldness of enterprise, decided that Hoosac mountain should be tunnelled for the passage of the canal.

When we consider the lack of experience, of mechanical facilities and especially the lack of capital in those days the proposed Hoosac tunnel of five miles length was a bold project and a far greater undertaking than would now be the seven miles San Blas canal tunnel which seems to have appalled, by its magnitude and suspected difficulties, the recent Isthmian Canal Commission.

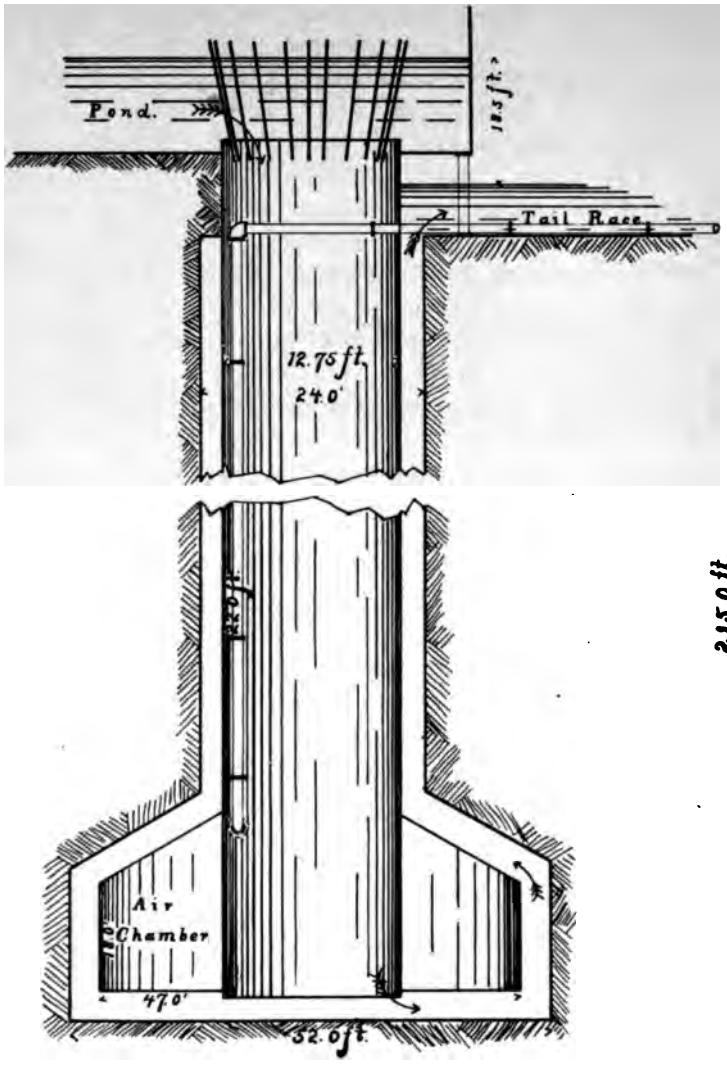
The incoming era of railroads defeated the canal project but the same route, practically, was adopted for a railroad and the Hoosac tunnel boring was commenced by hand drilling and at first progressed very slowly.

Hydraulic Compression of Air:—A dam was then constructed across Deerfield river near the east portal of the Hoosac tunnel to supply hydraulic power and this power in turn drove the newly invented Burleigh air compressors, of reciprocating pump form, which in turn compressed the air that drove newly invented rock drills within the tunnels and also aided in the ventilation of the tunnel.

This combination of hydraulic power and mechanically compressed air transmission of power, about the year 1865, greatly facilitated and enhanced the progress of the tunnel boring and greatly advanced the progress of the transmission of energy for power purposes.

The Hoosac tunnel was commenced earlier than any of the great railway tunnels now in use. It had been several years in progress when the Alpine Mont Cenis tunnel was commenced in 1857.

At Mont Cenis the process of air compression varied from that introduced at Hoosac. A small stream of water was util-



HYDRAULIC AIR COMPRESSOR.

ized with a fall of 85 feet and eleven plungers were used and the direct pressure of the water moved them forward in their reciprocations to compress the air to about five atmospheres. These water-column compressors were used several years and then abondoned and a reciprocating pump form of compressor substituted.

The success of air compressors and air drills at Hoosac led to their adoption in the chamber excavations in the Hell Gate rocks of the East river at New York.

Since then the construction of all the railway and mining tunnels of the world have been facilitated in speed of excavation

and economized in cost by aid of power storages and transmissions and by the energies of compressed air.

The new Croton aqueduct tunnel, which was about thirty miles in length through rock, was excavated in about two years time by the aid of compressed air and air driven rock drills.

The work of compression of the air is in part converted into heat and tends to increase the temperature of the compressed air and also to increase the volume that it would otherwise have at the given pressure, and thus tends to a loss of efficiency of the compressing machine. These results for a time practically limited the degree of compression to that of a few atmospheres even at low altitudes where compressors are most efficient.

An early devised remedy for the increase of the temperature of the air under compression was the injection of a spray of water into the compression cylinder which resulted in increasing the efficiency so as to save 5 to 8 per cent of power. Later the compressors were fitted with surface cooling devices to absorb the heat and permit the delivery of dry compressed air thus giving a further saving of about five per cent of the power. Later, compound compressors were supplied which effected the compression in several successive stages with surface cooling of the air at each stage.

These various improvements have brought the compressors to a fair state of efficiency for high pressures and to an economy that opens for them a large field of practical usefulness and to transmissions of power to longer distances than are economically practicable with hydraulic pressures.

Air Mains:—The method of computing the tensile strengths of the metal mains for air is similar to that used for hydraulic mains.

The effects of constant changes of heat in the air, from the beginning of its compression to the end of its motor work, makes the theoretical investigations of its pressure and frictions at its successive stages quite complex.

Fortunately, air at 80 to 100 pounds gage pressure has such slight density that it may be made to flow at considerable velocities through pipes without reducing the efficiencies of flow more than three to five per cent. Fortunately, also, air may be made to flow rapidly in the pipes without endangering them by water ram shocks.

As the air progresses along the pipe a part of its pressure is converted into work or heat in overcoming the reactions from the roughness of the pipe. As the pressure is thus reduced by frictions the volume of the air is increased and consequently the velocity through each unit of pipe length is increased. The fric-

tion of flow is therefore approximately as the length of the pipe and is as the square of the volume of flow and inversely as the diameter of the pipe.

Having the volume of air in cubic feet at 0. gage pressure for any given pipe it is observed that the volumes at greater pressures, isothermally considered, are inversely as the ratios of absolute pressures. Free air has 0. gage pressure. Let x equal another gage pressure and the ratio of compression is $\frac{(0.+14.7)}{(x.+14.7)}$ and the ratio of increase of cubic feet of free air isothermally compressed into each cubic foot of space in the pipe is $1 : \frac{(0.+14.7)}{(x+14.7)}$ If p^1 and p^2 are the initial and terminal pressures, in pounds per square inch, then the ratio of reductions of initial and terminal volumes of free air are $f_1 = 1 \div \frac{(0.+14.7)}{(p_1+14.7)}$, and $f_2 = 1 \div \frac{(0+14.7)}{(p_2+14.7)}$. The density of the compressed air, $w_1 = 2.7074 \frac{p_1+14.7}{t°+461^c}$, in which t equals the temperature of the air Fahr. degrees.

In long mains the velocity of flow of the compressed air should ordinarily be so limited that the decrease in pressure of the transmitted air will not exceed 2 pounds per 1000 feet or 5 to 10 pounds per square inch per mile length of air mains. This permits comparatively high velocities in the larger mains without excessive losses of efficiencies of transmission.

The volume of equivalent free air flowing in a pipe of given diameter and with given initial and terminal pressures is directly as the square root of the fifth power of the diameter, as the ratio of compression and the square root of the difference between the initial and terminal pressures, and inversely as the square root of the length of the pipe and the density of the air, hence the formula for volume Q is written,

$Q = C \frac{\sqrt{d^5} \times f_2}{\sqrt{l w_1}} \times \sqrt{p_1 - p_2} = $ = cubic feet per minute of free air.

From this we find by reduction the values of the several terms,

$(p_1 - p_2) = \frac{l w_1 Q^2}{C^2 f_2^2 d^5}$ = reduction of pressure in pounds per square inch.

$d = \sqrt[5]{\frac{l w_1 Q^2}{C^2 f_2^2 (p_1 - p_2)}}$ = actual diameter of pipe in inches.

$l = \frac{C^2 f_2^2 d^5}{w_1 Q^2} \times (p_1 - p_2)$ length of pipe in feet.

$C = \frac{\sqrt{l w_1} \times Q}{f_2 \sqrt{d^5} \times \sqrt{p_1 - p_2}}$ = coefficient from experiments.

The coefficient increases somewhat with both diameter of pipe and velocity of flow. For initial pressures 80 to 100 pounds per square inch and reductions of pressures of about 10

feet per mile length of pipe the coefficients for given diameters are approximately as follows:

For values of d.....	2″	4″	6″	8″	10″
Values of c.....	58.00	58.50	58.88	59.22	59.58
For values of d.....	12″	15″	18″	20″	24″
Values of c.....	59.90	60.42	60.94	61.30	62.00

Having Q and d given, or assumed, then for mean velocity of flow,

$$V = \frac{Q}{\frac{.7854\ d^2}{144} \times \frac{f_1+f_2}{2} \times 60} = \frac{Q}{.16363\ d^2\ (f_1+f_2)} = \text{feet per second,}$$

from which are derived,

$$d = \sqrt{\frac{6.1115\ Q}{(f_1+f_2)\ v}} = \text{diameter of pipe in inches,}$$

$$Q = \frac{d^2\ (f_1+f_2)\ v}{6.1115} = \text{equivalent free air in cubic feet per minute.}$$

The following table illustrates results given by the above formula for Q, when the length, l, is assumed constant at 1,000 feet and the initial and terminal pressures constant at 100 pounds and 98 pounds, and also 85 pounds and 80 pounds, respectively:

COMPUTED VOLUMES OF FREE AIR WHEN l = 1,000 FEET.

Nom. diam. of Pipe.	Section of Wrought Pipe.	Coefficient.	Volume of Free Air for reduction of pressure from 100 lbs. to 98 lbs. (p_1-p_2) =2 lbs.	Velocity of Flow.	Volume of Free Air for reduc. of press. from 85 lbs. to 80 lbs. (p_1-p_2) =5 lbs	Velocity of Flow.
d in Inches.	Sq. feet	C.	Cubic feet per minute.	Feet per second.	Cubic feet per minute.	Feet per second.
2	.0233	58.00	155.77	14.659	264.17	24.86
4	.0884	58.50	831.84	20.634	1,410.72	34.99
6	.2006	58.88	2,332.09	25.491	3,954.98	43.23
8	.3475	59.22	4,660.66	29 412	7,904.01	49.88
10	.5475	59.58	8,276.78	33.152	14,036.6	56.22
12	.7854	59.90	13,064.1	36.477	22,155.4	61.86
15	1.2989	60.42	24,705.6	41.722	41,898.2	70.76
18	1.7691	60.94	36,625.1	45.450	62,112.5	77.08
20	2.6398	61.30	47,944.0	48.192	81,308.2	81.73
24	3.1416	62.00	76 472.5	53.394	129.724.0	90.25

The volume of air flowing increases as the difference (p_1—p_2) between initial and final pressures increases.

The volume of air flowing decreases as length of pipe is increased. The table shows maximum advisable velocities of flow and for the given initial pressures and reductions of pressures the maximum advisable volumes of flow in the given sizes of smooth pipes.

Air Motors: In the installation of new compressed air systems in cities there is great advantage in being able to apply the energy of the air directly in ordinary steam engines, such as are

usually found in operation and even without necessarily changing their valves or port openings. In such works as the Jerome Park reservoir large numbers of portable steam engines were used with air instead of steam pressures to operate the derricks. Automatic cut-off movements for the valves enhance the economy of air as they do of steam, and efficiencies of air motors are enhanced by expansion appliances such as give the best steam efficiencies.

In good practice the efficiencies of such compressors as are provided with effective cooling apparatus should be as much as 80 per cent, and of mains 95 per cent, thus reciprocating motors when reheated air is used 80 per cent, thus giving the air mechanisms final efficiencies of 60.8 per cent.

When first-class turbine water wheels are used to drive the compressors then approximately 50 per cent of the theoretical power of the water should be realized from the terminal work of the air motor.

Water Weight Compression of Air: On the Quinebaug river in Connecticut, near the City of Norwich, there has been recently constructed a water compressor of air on the Taylor system.

A new dam and forebay has been constructed on the river for the purpose. The ordinary flow of the river is estimated to be 608 cubic feet of water per second and the usual head of water 18.5 feet. If first-class turbine wheels were here used they should give an aggregate of about 1141 horse powers from their shafts.

The dam is arranged with a forebay at one end adjoining which is a tail race constructed much as is usual at hydraulic powers. But, as turbines are not used in this air compression plan, a deep shaft is sunk from the rock floor of the tail race at the place where the turbine usually stands. In this case the shaft is sunk in the rock to 215 feet below the usual surface of the tail water. This vertical shaft in the rock is 24 feet in diameter nearly to the bottom where it is enlarged to 52 feet in diameter.

Within the rock shaft there stands a steel cylinder which is 12.75 feet diameter, extending nearly to the bottom of the shaft, where it is surrounded by an enlarged cylinder 47 feet in diameter. This last enlarged cylinder is about 18 feet high and is joined to the 12.75 foot cylinder by a conical section inclined like a roof at about 45 degrees. Both steel cylinders extend nearly, but not quite, to the bottom of the shaft and both cylinders are open at the bottom. There is a clear space between the rock shaft perimeter and the steel cylinder. The 12.75-foot diameter cylinder extends up through the tailwater and just through the forebay floor and its top is open to receive a flow of water from the forebay. The top of the steel cylinder is ordinarily seven feet submerged.

Considering now the flow of water through this ponderous but simple apparatus we observe that the water flows down the steel shaft and under its bottom and under the enlarged steel chamber which forms a domed air vessel, and then out under the shell of the enlarged cylinder and up between the cylinders and the outside of the rock shaft into the tail race and then away down stream, as shown in cut on page 8.

Considering the process of air compression in this apparatus, we observe that around the top of the steel cylinder where the water flows in there is fitted a special head which is adapted to break up the solid inflowing stream into numerous parts or sprays and around the sides of this head there are numerous small pipes to lead air into the midst of the down-flowing stream of water. The partial vacuum or tendency to a vacuum, under the lower ends of the small pipes draws in air which is entangled in the water and carried down the shaft with the current.

As the water passes under the bottom of the steel shaft into the surrounding steel air chamber the air escapes from its surface into the air chamber, while at the same time the water escapes under the bottom of the air chamber shell and up the rock shaft into the tail race. This air dome at the foot of the rock shaft is submerged to a depth of 197 feet below the surface of tail water. The air in the dome is consequently compressed with a pressure equal to 197 feet head of water or equal to 85 pounds pressure per square inch.

The air when thus compressed has energy to work and may be piped away to where there is work for it to do and it is cooled to the temperature of the river water as well, and is adapted to work in any kind of air engine or even such as are ordinarily used for steam, at a pressure of from 80 to 85 pounds per square inch, at any point to which it is piped within a radial distance of ten miles from this compressing plant. The projectors of this plant expect it to show a compressing efficiency at least equal to the best four stage mechanical compressors when such are driven by turbines or steam engines.

A Taylor compressing plant is in successful use at Magog on the Magog river in the Province of Quebec, and at Ainsworth, in British Columbia. The Magog plant has a capacity of 155 horse powers and, in August, 1896, superceded steam in operating six cotton cloth printing machines. The Ainsworth plant was designed to develop 500 horse powers and to distribute its energy to work in the mines within a radial distance of five miles.

At the Quinnesec Falls, in Michigan, there is a 2,000-horse power hydraulic air compressing plant. Here are installed a group of eight compressors. The compressed air is led in a

24-inch pipe 3.5 miles to the Chapin mines where its energies are devoted to operating rock drills, to pumping and to the various needs in deep mine shafts.

Compressed air locomotives are having extended use for hauling in mines, lumber yards, goods warehouses and among buildings where fire risks might be excessive by sparking motors or wires.

The Compagnie Général des Omnibus has about sixty miles of steel tram cars in use in the City of Paris. The cars have accommodations for fifty passengers each.

The compressing plant at La Villette station employs the three stage Mékarski system which is capable of a compression of the air to 1120 pounds per square inch. The air is reheated on the car by passing it through hot water before it is used in the motor.

The lines of compressed air cars on the 28th and 29th street cross town lines in New York and on North Clark street in Chicago are familiar examples of street car systems.

These few examples illustrate that in its special fields compressed air has become widely useful and one of the most valued vehicles for energy transmission and its sphere of action is broader than that of any power transmission by which it had been preceded.

Commercial Air Systems:—The city of Birmingham, England, has a noted compressed air plant that distributes energy for miscellaneous work about the city.

The most conspicuous of plants for general distribution of energy by compressed air is that at the Quai de le Gare, in Paris, with pipes 4.5 miles in length and 20 inches diameter and transmitting 6,000 horse powers generated by steam driven compressing machinery.

In recent years no great railway tunnel, mine, blast furnace, foundry, machine shop or structural steel plant has been without its air compressing plant to gather and transmit energy to its destined work, with equal facility whether the work is near or distant.

The rock drillings and hoistings at the great Jerome Park Reservoir, in New York, by the Chicago Drainage Canal, by the New York Under Ground Rapid Transit tunnel, have been compressed air works, and further there may be cited the extensive air compressing machineries of the Anaconda Copper Mining Company, at Butte, the Passaic Rolling Mill Company, the Kelley Island Lime Company and the Delaware Breakwater as a few noteworthy examples of central compressed air power transmission plants.

Electric Currents:—Considering now the most recently developed transmissible energy and the energy transmissions that have made the last decade notable in engineering annals we find that their fields of usefulness are far broader than those already discussed. We refer to the alternating polyphased electric currents generated when the energy transformed through the turbine or steam engine revolves the cross wound armature within the magnetized field of the electric generator, or the field within the armature, and there flows into the wires of transmission a mysterious electric fluid that has marvelous properties and energies.

Hydraulic Powers Electrically Transmitted:—Excellent examples of the results we have been considering are seen at the St. Anthony Falls Water Power where work goes to the power to the extent of nearly one-half million bushels of wheat weekly to be milled into flour, and where there is generated both direct and alternating currents that go out over 225 miles of street railway tracks to perform the great works of driving the respective trolley cars of the Twin Cities, at which ever point they are moving.

A notable plant, generating current for electric transmission, is located on the Missouri river near Helena, Montana. Here a dam thirty feet in height flows a broad river basin forming a lake of 3500 acres which extends seven miles up the stream. In this storage lake the flow of the river may be amply stored so as to provide for intermittent daily use of the river flow for power without water being wasted. The power house is of granite masonry and contains ten sets of turbine water wheels to which are direct connected ten alternating current generators of about 10,000 horse powers aggregate capacity.

The entire plant represents an investment exceeding $2,000,000. From the power house a double pole line and copper cables extend eighteen miles to Helena and South Helena and also sixty-five miles, crossing the Rocky Mountain continental divide to the city of Butte.

These transmission lines required about 1,000,000 pounds of copper cables and 7,000 cedar poles.

About one-third of the power is transmitted electrically to the Helenas for street railway work, city lighting and miscellaneous power work and the remaining two-thirds of the power the longer distance to Butte, at 50,000 volts potential and this latter power is applied to the lighting and miscellaneous work of a city of 35,000 inhabitants and to the works of the most extensive mining and smelting camps in existence.

supplied to the trolley rails in the open conduit street system. On completion of the plant one year ago 1,200 cars were operated by the electrically transmitted power on 80 miles of track.

Also, in New York City, may be seen the nearly completed installation of the Manhattan Elevated Railway Company's plant.

Electric currents from this station will displace some 225 locomotives used on the elevated road last season. The electrical currents required from this station will be quite variable but its estimated mean is 30,000 electrical horse powers and its maximum 60,000 electrical horse powers. These alternating currents will be transmitted first to the several sub-stations, stepped down, and then sent by a third rail transmission over all the elevated system.

There are being installed in this station eight steam engine units of 8,000 rated horse power capacity, aggregating 64,000 horse powers and each engine is capable of fifty per cent overload. Eight alternating current generators are direct connected to these engines which have an aggregate normal capacity of 40,000 kilowatts. These last will generate electrical current at 11,000 volts potential, when it will be transmitted to the seven sub-stations.

The New York Edison Company station, now nearing completion and partly in service, is to generate electric currents for lighting and power purposes.

The rated normal capacity of this station is 90,000 indicated horse powers with possibility of working up to 128,000 horse powers. The direct connected generators are of the alternating three-phase current type and deliver current at 6,600 volts potential and this is transmitted to many sub-stations. This power station has 56 units of boilers of 650 horse powers each the units being set in two double deck rows. There are sixteen vertical, compound, condensing steam engines of the three-crank type, with one high and two low pressure cylinders each. Each engine has an economical capacity of 5,000 horse powers and can work to 8,000 horse powers. Each generator is on the end of an engine shaft. From the many sub-stations in different parts of the city the current, expected to aggregate 100,000 horse powers, will be transmitted throughout the city for lighting and power purposes.

The era of great central stations for general power distributions is already well inaugurated and they will be multiplied in the years now coming.

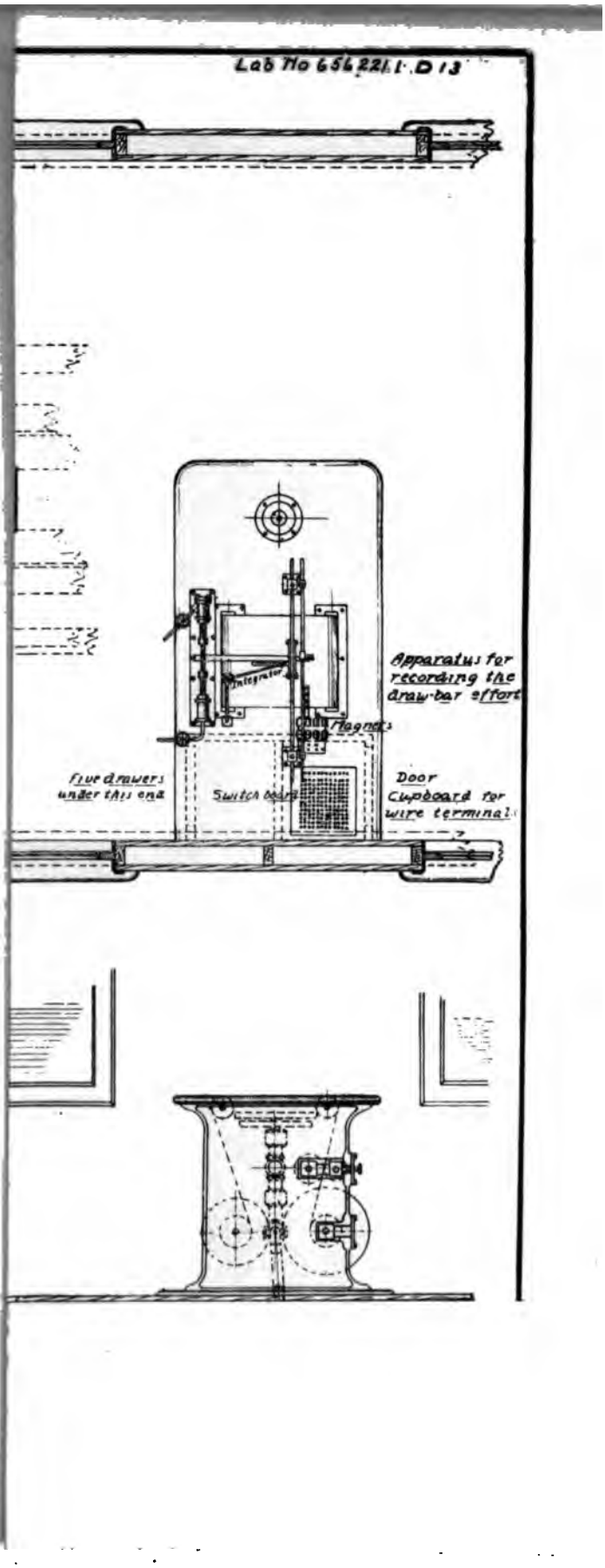
Adaptabilities:—Thus have progressed the evolutions in the useful applications of energies through a series of achievements, rapid in succession and each more remarkable than the last.

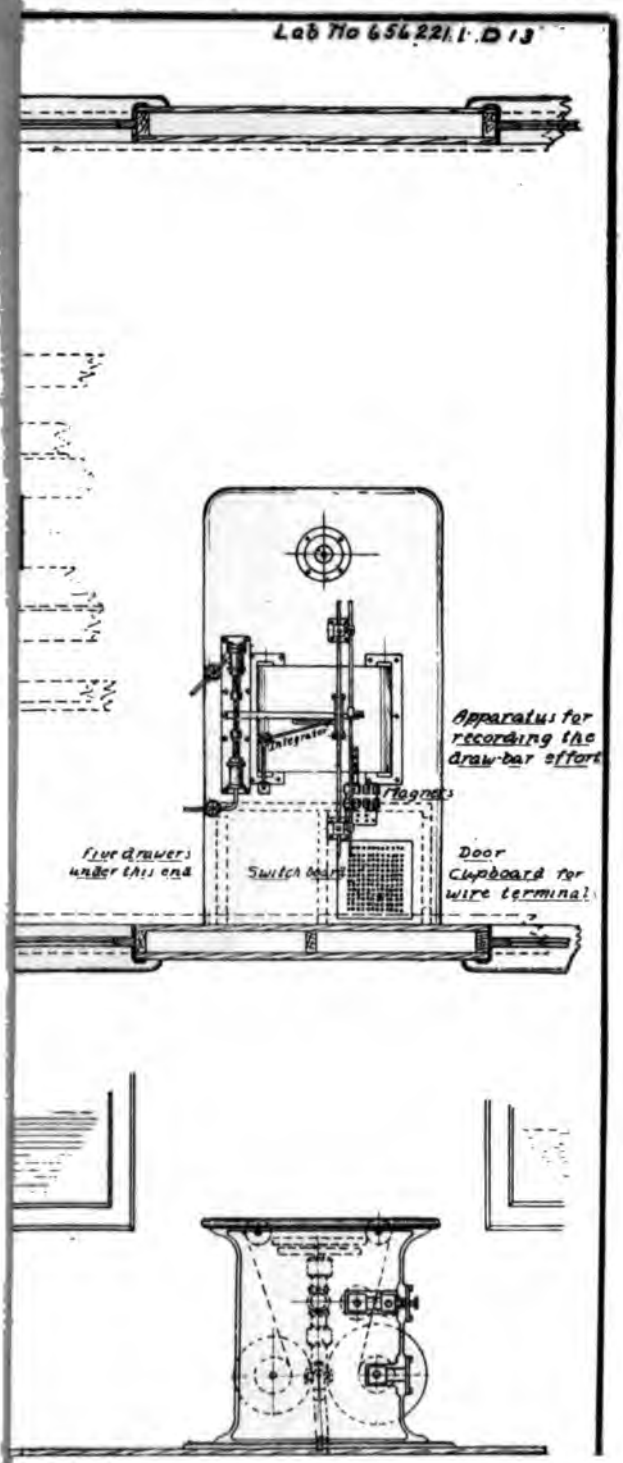
The adaptabilities of the several forms of power transmission reviewed are varied and each engineer has to choose which will best serve his special purpose. He must be familar with their respective merits and keep in touch with their rapid improvements. This review has therefore had the object of making more familiar the practical uses to which these respective forms of power transmission are best adapted and their possibilities.

It is a meritorious task to tame and harness a spirited young horse and make him our assistant worker. It is a more admirable task to curb and guide a great river into our turbines on its shore and make the river our assistant worker with the power of many thousand horses. It is still grander to make the mighty river send its energies ten, fifty or one hundred and fifty miles away and become, at a distance, an assistant worker for the benefit of a whole community in the midst of their homes.

In ancient Scriptural language it is inquired of Job: "Who hath divided a water course for the overflowing of the waters," and "Canst thou send the lightnings that they may go, and say unto thee 'Here we are.'"

Our story has led direct to practical answers to these inquiries by men who have seemed inspired with powers almost divine. Our story has led, also, along a series of typical practical achievements to the close of the recent century and to the point where the graduating classes in Engineering of this year are to take up the work and, with the impetus which the past generation has given, carry it forward to such far more wonderful achievements as none at present would dare predict.


Lab No 654.221.1.D 13
Apparatus for recording the draw-bar effort
Magnets
Five drawers under this end
Switch board
Door Cupboard for wire terminals


Lab No 654221.1.D13
Apparatus for recording the draw-bar effort
Five drawers under this end
Switch board
Door Cupboard for wire terminal

THE BURLINGTON TEST CAR.

C. C. HIGGINS, Minnesota, 1900.

The primary object of the car is to determine the pull or push at the draw by means of a dynamometer, and get a continuous record of the same.

This car was originally built in about 1885 and equipped with a twin spring dynamometer and a recording device. Owing to its small capacity and some mechanical defects, the dynamometer was replaced by one of the hydraulic pattern. This was done in Aurora, Ill., during July and Aug., 1901, under the supervision of J. F. Deems, Supt. of Motive Power, M. H. Wickhorst, Engr. of Tests, and the writer. Other features were added at this time consisting of apparatus for making boiler tests, air brake tests, as well as a chemical flue gas analysis apparatus.

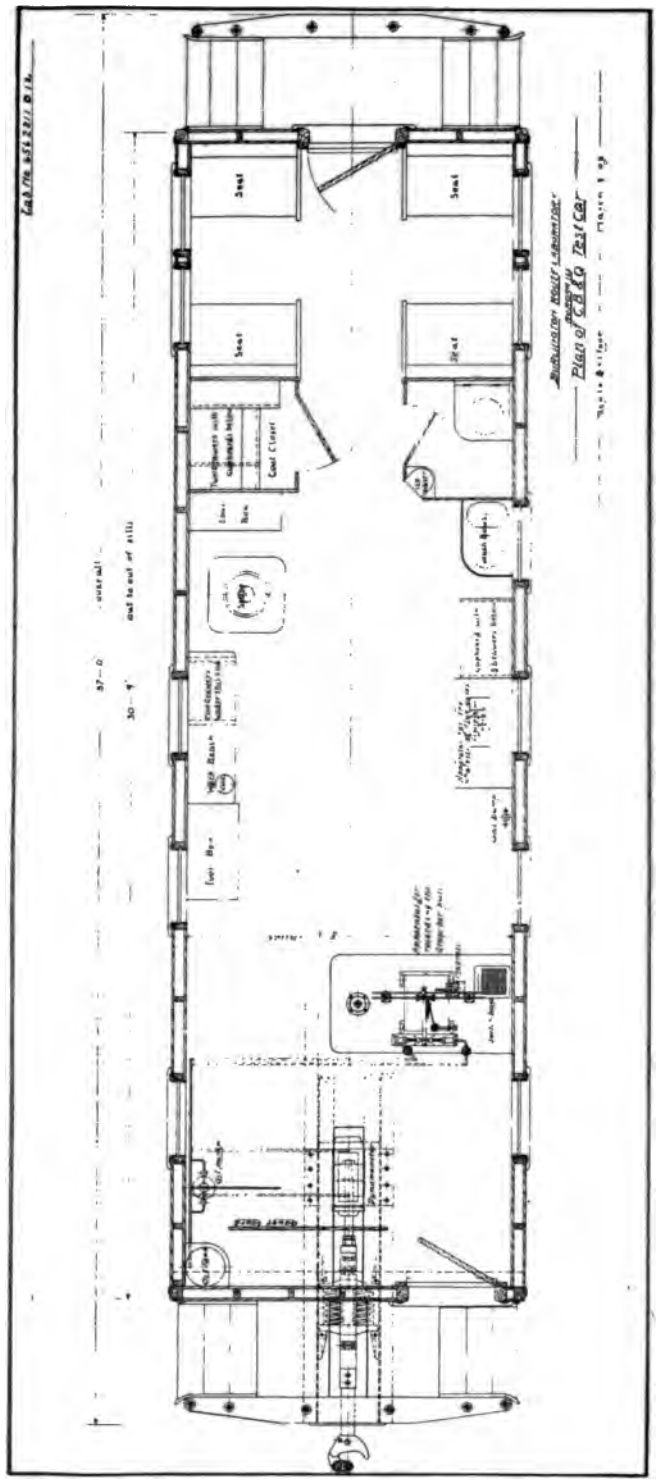
The car is 30 feet, 9 inches long outside of the sills and 8 feet, 6 inches wide inside. Near the front end is a standard cupola for observation purposes. The dynamometer and other apparatus occupy the front half and the rear of the car is used for sleeping accommodations.

The dynamometer consists of a cast iron cylinder 10 inches diameter with a cast iron piston head ground to a perfect fit. There are no packing rings nor leathers whatever. Small grooves are turned in the piston to retard the leakage. The piston rod is ground to fit a cast iron gland and packed in the same way.

The rod is attached to the couple or draw bar by means of a specially designed yoke. Two springs within the yoke constitute a safety device, and are so arranged that the pull or push will be taken up on them and they completely compressed before the piston comes to the end of its stroke.

The piston has a free travel of four inches and will move forward slightly on account of the leakage of the oil. No trouble has been experienced by this for it has been found that with the heaviest freight pull on a 100 mile division the piston would not travel forward more than two inches.

Iron distance pieces two inches thick are put in between the springs and the blocks on the yoke when the dynamometer is out of use as in the case of sending the car some distance "deadhead."


Plan of Cafe Parlor Car
Seat
Seat
Seat
Seat

The tendency to form a vacuum on the back side of the piston caused by leakage or any pressure is relieved by suitable arranged check valves.

Three Ashcroft hydraulic gauges are connected to the oil system; one high pressure of 1,000 pounds, one 1,000 pounds for test purposes, and one reading 14.7 pounds vacuum and 60 pounds pressure.

The recording apparatus is placed on a table near the front end of the car and consists of two cast iron cylinders 12 inches

INTERIOR OF BURLINGTON TEST CAR.

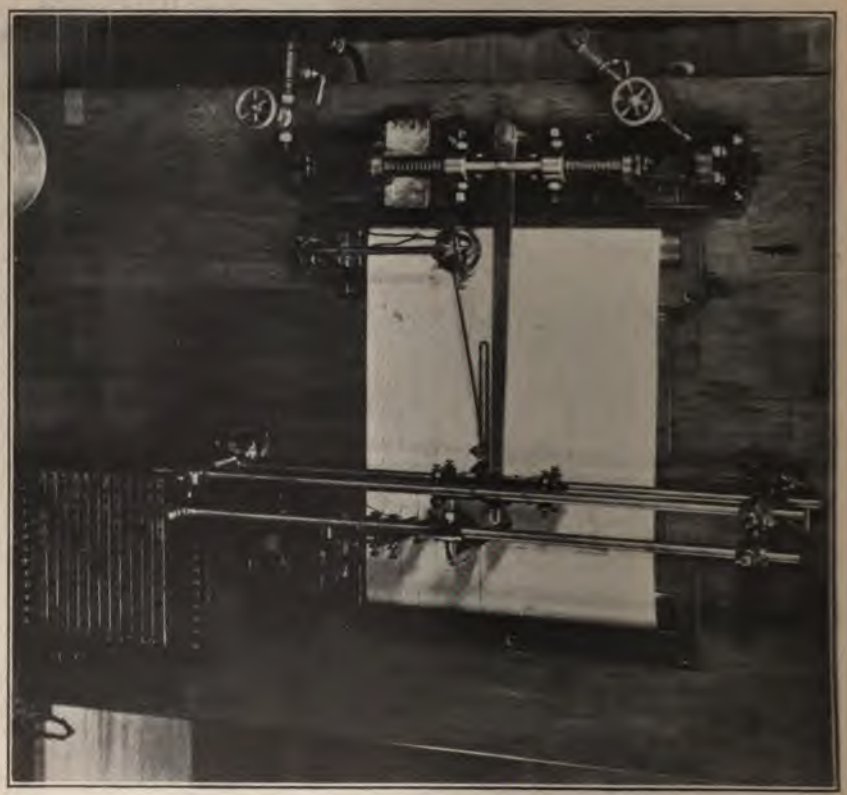
apart with a piston rod ¼ square inch area extending from one to the other. One cylinder has a ¼inch pipe connection to the front end of the dynamometer and the other cylinder is connected to the back end. The oil pressure is resisted by helical springs clamped on the piston rod and each spring is compressed to half its maximum deflection. This is done to equalize the irregularities that exist in a helical spring.

Three sets of springs are used. These are of such capacity that a six-inch ordinate is secured with a draw bar pull of 10,000, 18,000 and 24,000 pounds respectively.

The motion of the indicator piston rod is transmitted by an arm pivoted at one end of the cylinder casting working on a pin in the piston rod through a slot in the arm. The deflection is multi-

plied ten times and the long end of the transmission arm is slotted and runs on a pivot fastened to a carriage on rollers, these in turn running on two ½inch round iron guide bars. A stylographic pen is attached to this carriage to record the deflection. Another similar pen is adjusted to remain stationary at the zero point, and is called the datum line pen.

A continuous record is obtained on a roll of paper 14 inches wide driven from gears attached to the car axle. This can be

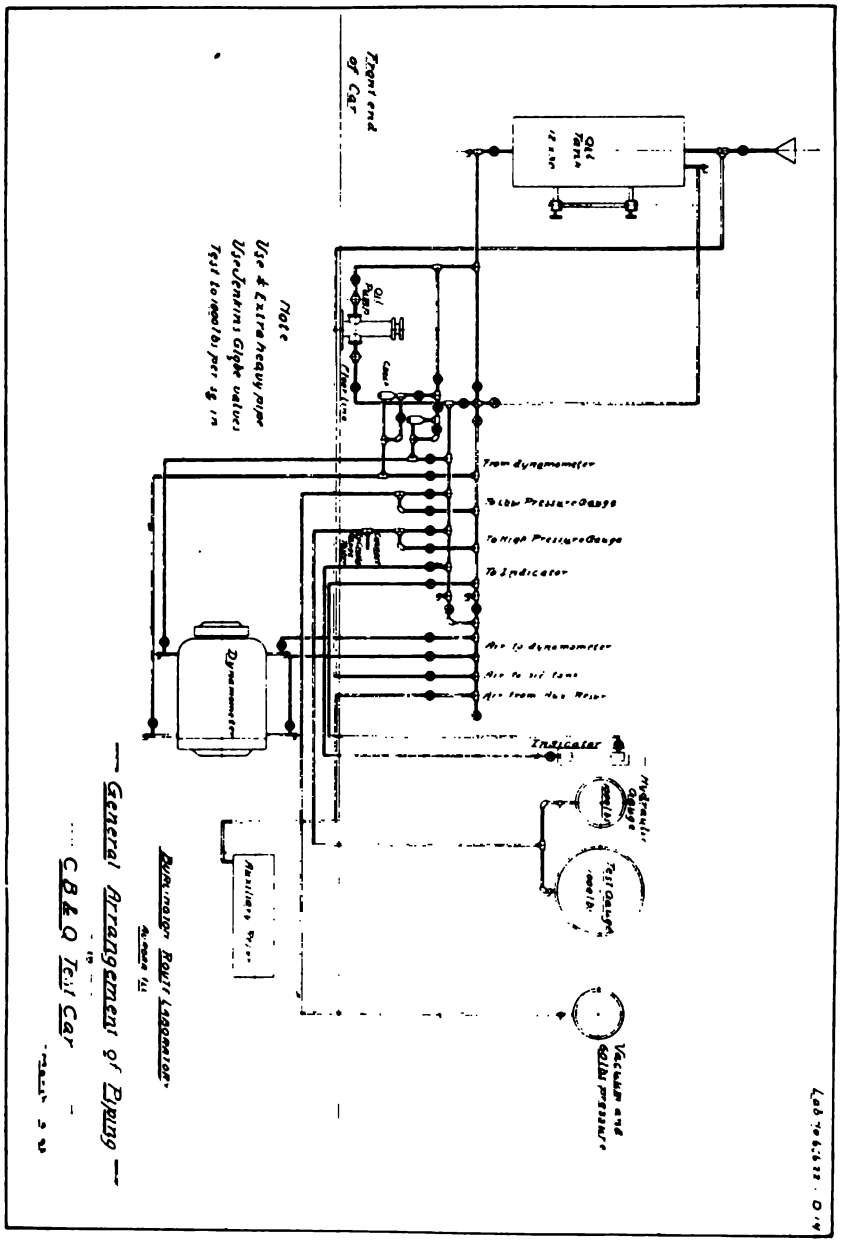


Top View of Recording Apparatus, Burlington Test Car.

adjusted to give a speed of one foot or two feet of paper to one mile of track.

Four double-acting electro-magnets are placed beside the paper in line with the dynamometer recording pen and with a stylographic pen attached to each armature. When the electric circuit is closed it causes the pen to be moved out of a straight line, making a jog or a notch.

One pen is used to record mile posts and stations from a push button situated in the cupola and operated by an observer placed there for that purpose. Another pen is used to obtain a record of speed and time by connecting to a specially designed clock which


Front end of Car
Note
Use 4 Extra heavy pipe
Use Centrifugal Globe valves
Test to 1000 lbs per sq in
Oil Tank
Oil Pump
Condenser
From dynamometer
To Low Pressure Gauge
To High Pressure Gauge
To Indicator
Air to dynamometer
Air to oil tank
Air from Aux Motor
Dynamometer
Indicator
Hydraulic Gauge
Test Gauge
Auxiliary Motor
Vacuum and Water pressure
Lab 96 1/2 x 22 - 0.14
Burlington Route Laboratory
General Arrangement of Piping
C.B. & Q. Test Car

makes an electrical contact each five seconds. A record can also be kept of the time of taking indicator cards, the reverse lever and throttle positions, etc.

Attached to the dynamometer recording pen carriage is a mechanical integrator, which is simply a planimeter of special design. A 1½inch wheel rests on the paper and runs on a pivot bearing. The frame carrying the wheel is on an axis free to turn in a plane parallel to the paper, this axis being in line with the vertical diameter of the wheel. A 9½inch arm attached to the wheel frame has a pivot bearing in the other end which is free to run in a slotted arm attached to the dynamometer recording pen carriage. The axis of the integrator wheel is normally parallel to the line of direction of the paper, and hence any motion of the paper will not tend to turn the wheel. As the carriage is moved the axis of the wheel is changed and the moving paper turns the wheel, thus measuring the area between the zero line and the line of draw bar pull. A wheel with 20 contact points is placed on the shaft with the integrator wheel and an electric connection is made to one of the magnets which gives a continuous record of the area. This divided by the length passed over gives the height of mean ordinate. It is constructed that one contact or notch indicates 2.243 square inches of area.

For calibrating the dynamometer recording apparatus a Crosby dead weight gauge tester is introduced into the system. Pressure obtained by an oil pump is maintained by the gauge tester and transmitted to the recording apparatus. A number of points are thus found at pressures of from 10 to 250 pounds per square inch. This pressure multiplied by the net area of the piston gives the draw bar pull for a given ordinate. A line is plotted showing draw bar pull vertically and inches deflection of the recording pen, horizontally. The datum line and the zero line of the recording apparatus are checked up at the beginning and end of each trip.

An electrical switch board is placed on the table and arranged so that any push button can be "plugged in" on any magnet. Under the switch board is a terminal board where all wires are brought and labeled; this to assist in finding breaks and faults.

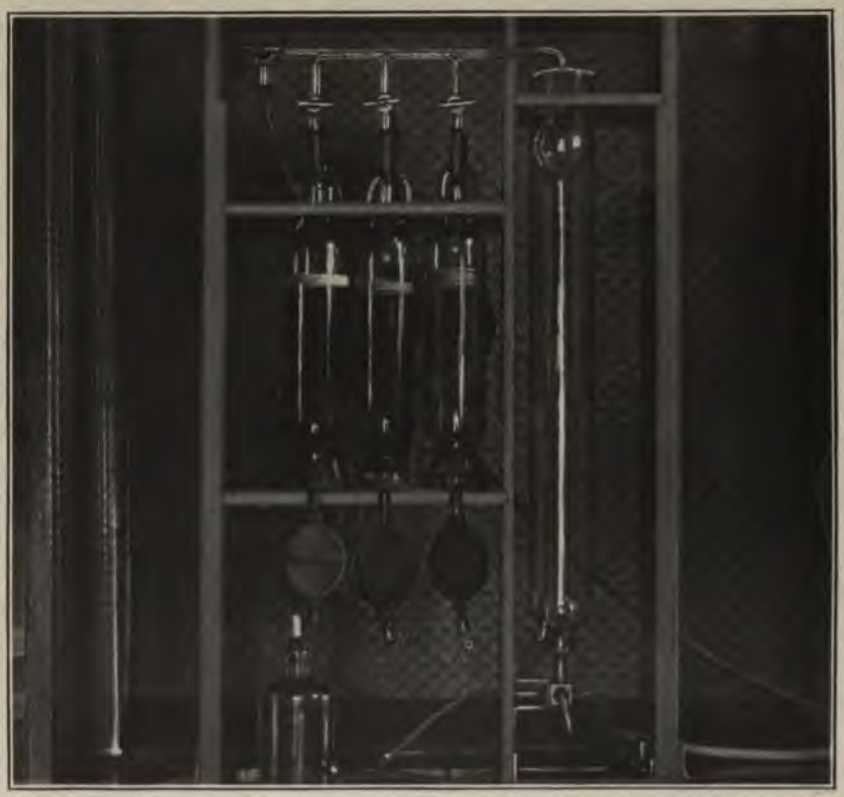
Electrical power is derived from 30 sal ammoniac cells placed two cells in series and five such sets placed in parallel, thus making three units. These are in turn connected to the switch board.

There are three Schaeffer & Budenberg electric counters of five figures each, which are used to count revolutions, strokes of the air-pump, etc.

All the gauges, electric counters, and clock, are placed on one board for convenience.

In addition to these already mentioned are a duplex air gauge, showing train line pressure and brake cylinder pressure; a locomotive steam gauge of 300 lbs. pressure; and three 14inch Crosby recording gauges. These are of special design and have a clock adjustment giving a revolution in 3, 6 or 12 hours. One is used for recording train line pressure, one for smoke box draft or vacuum in inches of water, and one for boiler steam pressure.

A Boyer speed recorder is also used for indicating speed in miles per hour.



APPARATUS FOR GAS ANALYSIS.

One of the most important of the late additions is an apparatus for the analysis of flue gases. This consists of Bement's arrangement of an Orsat gas analysis outfit. The gas is pumped back to the car from the locomotive smoke box by a vacuum pump through a ¼inch pipe and a sample caught in the apparatus. An analysis is then made to determine the per cent of car-

bon di-oxide, ($C O_2$), oxygen or air (O), and carbon monoxide (C O). One operation takes about 15 minutes.

Among the tests made recently are: tests of curve resistance, friction of side and center bearings on freight cars; boiler, indicator and dynamometer tests of simple and compound engines in freight and passenger service.

The car has been in constant use since its completion last September and enough work is in sight now to keep it in active service for another year.

We wish to express our thanks to Prof. L. P. Breckinridge of the University of Illinois for demonstrating the feasibility of the hydraulic and also for the gift of his drawings of the Illinois Central Test Car.

STADIA WORK ON THE ST. LAWRENCE RIVER.

By FRANCIS C. SHENEHON.

During the latter part of the field season of 1901, the writer in charge of the St. Lawrence River division of the United States Lake Survey, made surveys of a reach of about forty miles of this river, from St. Regis to Johnstown. The original surveys for the navigators' charts had been made thirty years before, and the new work to modernize these utilized the old triangulation system as a skeleton to hang the new details upon.

As the survey required the land features of a zone reaching perhaps a quarter of a mile back from each shore line, as well as soundings in thirty miles of the main river channel, the work was both topography and hydrography.

Ordinarily stadia locations obtain in topography, but in hydrography less facile methods are customary. The extraordinary element in the St. Lawrence River work was the extension of the stadia method to the location of soundings.

By land the approved method was used of transit circuits, starting at a triangulation station of known co-ordinates, with known azimuth, and proceeding with many zig-zags, meandering for advantageous transit positions to embrace all shore features, and finally bringing up at a second triangulation station, of known location. Of course secondary circuits were swung from the main line, when desirable, and sometimes spurs branched for a station or two from these. Having in mind that the sounding party would follow, the land parties included in their work the location of shore stations, which were marked by drill holes in boulders, or by monuments; and azimuth was perpetuated for these hydrographic stations by reading in from each of them the direction of two or more fixed targets such as church steeples, chimneys, or gable ends of houses or barns.

One topographical party occupied the Canadian side and one the American; and the work of the two parties was interlaced by cross-river shots from the hydrographic stations.

The waterway over this river reach will perhaps average three thousand feet in width, and in many places is split up into several channels by islands. It is somewhat sinuous, and is flowing along with a current as fast as ten miles an hour in some navigable places, is characterized by strong eddies, and breaks into white horses in the rapids Galops, Plat, and Long Sault,

making a descent of ninety feet in forty miles, as it swings towards the sea over a bed of granitic boulders.

The shores are gently undulating, open farming lands for the most part. On the Canadian side for twenty-three miles of the way the river is skirted by the Canadian ship canals, which largely increased the details to be surveyed.

Each land party consisted of six men,—chief, transitman, recorder and three rod men. The chief maneuvered the party and planned the advance, carrying a drawing board (½ x 11½ x 16 inches, white pine) covered with cross-section paper on which he sketched freehand the topographical features of the country traversed. The transitman in addition to manipulating the instrument, directed the rodmen when necessary. The recorder kept the instrumental notes. Each rodman carried a tablet and noted the number and character of his shots. At night the sketch of the chief, the notes of the recorder, and the minutes of the rodmen were compared and connected, and stadia readings were reduced to distance.

Meanwhile an advance party relocated the stations of the old triangulation system and established hydrographic stations, setting signal flags at each; and an office party platted the field notes and endeavored to keep the detail maps close behind the field parties.

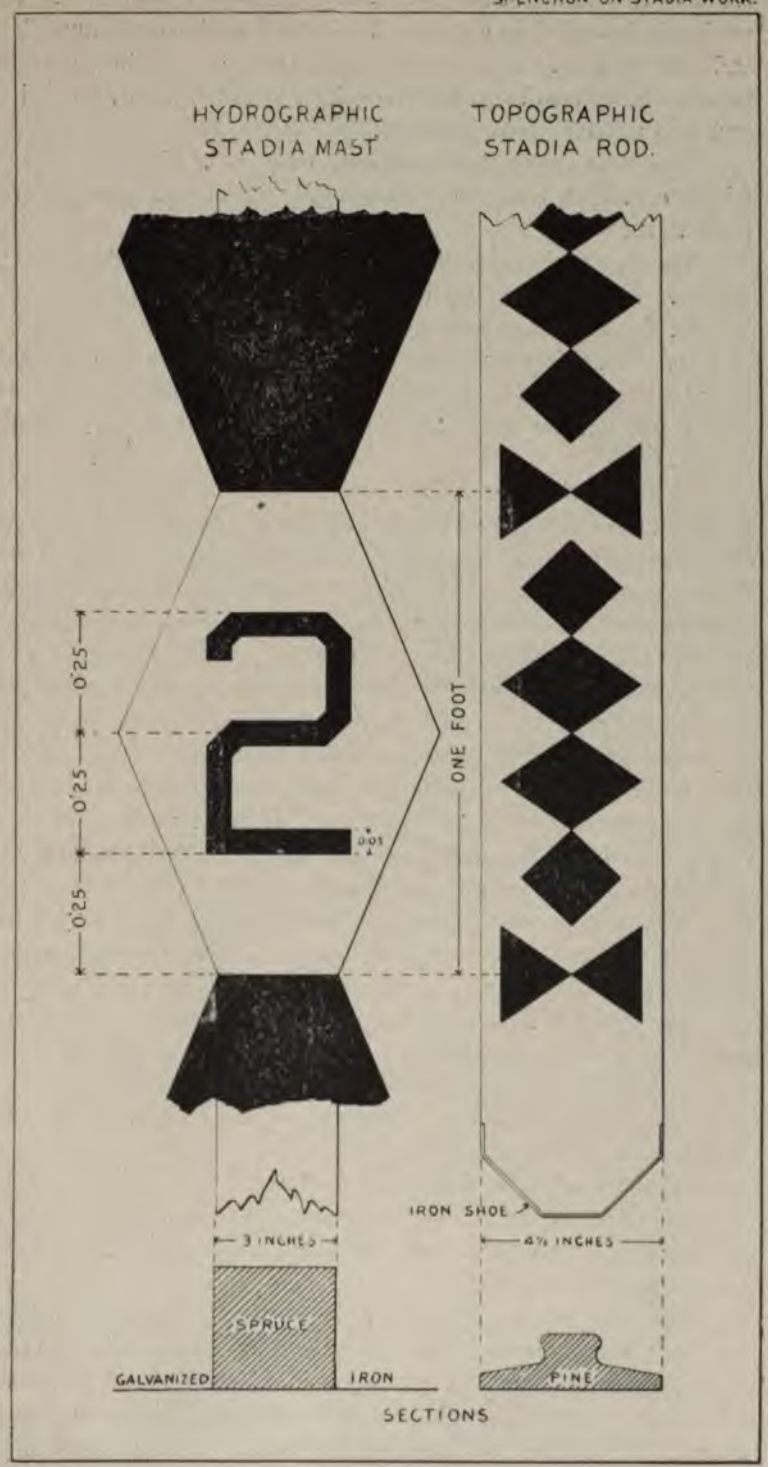
This outline of the nature, conditions, scope and general methods of the work, leads up to the detail with which this paper deals, namely, the stadia.

The stadia is part of the wizardry of surveying. The tedious trailing measuring chain is discarded for lines of light. It appeals to the imagination as wireless telegraphy does, and by analogy might be called "chainless surveying." It is entering new fields and widening its scope. Recently American engineers ran a preliminary location line for a railway in China, 742 miles in length by stadia alone.

This single circuit between two points located astronomically checked within half a mile, giving a precision of about 1 in 1500. The practicability of the application of the stadia to hydrography may be regarded as demonstrated for similar conditions by the work on the St. Lawrence. For both hydrography and topography ordinary surveyors' transits were used, with fixed wires showing an interval of nearly one foot to the hundred.

The design of the stadia rods used in topography is shown in accompanying plate. The rods were fourteen feet in length and struck from clear, well-seasoned, straight-grained white pine by mill machine knives, as mouldings are. The cost of the ma-

SHENEHON ON STADIA WORK.



chine work was about two cents a running foot for six rods. The section is intended to give a rod stiff and at the same time light and easy to grip. The rods however showed a slight curvature after some use, and for future designs two inch stuff, instead of inch and a half is recommended.

The rods were sand-papered, then painted three coats of white lead, each coat being thoroughly dried and sand-papered prior to the next.

The graduation was that used in the U. S. Deep Waterways survey. It seems the clearest-cut of all diamond and triangular figures. Such a design however as is shown in *Engineering News* of Feb. 20th, this year, consisting of square blocks and showing the number of the foot-lengths in large figures has many advantages, and will be tested in the surveys in my charge another season.

In graduating the rods it was decided to mark them all in foot units, instead of making graduations to fit the wire intervals of each instrument. While this method requires the use of factors or constants to reduce even level shots to distance, it seems sounder than the old method, and proved peculiarly adapted to this work because the stadia mast used later in hydrographic work was read alternately by two instruments with different intervals. In this case an interval factor was necessary, whether or no, and it proved exceedingly facile in land work as well.

The rods were first laid off in even feet, beginning half a foot from the bottom, with a steel tape. With a template cut from heavy card board the diamonds and triangles were outlined, and were penciled in accurately with a try-square and a bevel-square. The figures were next outlined in black paint,—*using a rightline pen, not a brush*—then the interiors were filled in black with a brush.

The initial field stadia work was the calibration of the instruments, to find the wire interval factor, to reduce readings to distance. For this purpose a stadia circuit was run between two triangulation stations, whose co-ordinates were known, and each course was measured accurately in duplicate with a steel tape. This calibrating base was taken as fairly representative of the character of the country to be surveyed. It consisted of meadows, cultivated land, pastures and brush land, with some undulation—but no water crossings.

Readings were taken over this during part of the ordinary working hours of two days, running back and forth from station to station. This was late in June. Not a little of the reason for using this calibrating base was the desire to give new transitmen a little practice with instruments before undertaking detailed

surveys; as the calibration of the instruments may be derived from the closure on triangulation stations using assumed interval unity, without special calibrating work.

The observations and their reduction are of interest. Inclined shots were first reduced to level and the (c+f) constants of each instrument (See Johnson's Surveying, page 247) subtracted from each chained distance; the eleven courses resulting in eleven equations of the form.

$$\text{(Chained distance)}-(c+f) = m\ \text{(Stadia reading)} \quad \ldots\ldots (1)$$

$$\text{or Interval Factor} = m = \frac{\text{(Chained distance)}-(c+f)}{\text{Stadia reading}} \quad (2)$$

The mean of all shots back and forward for each course was taken as a single observation of weight unity. The results for the Gurley transit are shown in the following table.

Table 1.—Computation of Interval Factor.

Course.	Number of Shots.	Chained Distance	Stadia Reading.	Vert. Angle.	Stadia corrected for Angle.	Distance minus (c+f).	Interval Factor m.	Residuals.
a	b	c	d	e	f	g	h	i
1	5	767.0	777.6	1-12	776.2	765.9	0.9867	+0.0021
2	6	1205.4	1223.0	0-24	1222.9	1204.3	.9848	+ 3
3	6	1190.0	1204.7	0-08	1204.7	1188.9	.9869	+ 24
4	6	507.0	512.3	0-17	512.3	505.9	.9875	+ 30
5	6	1017.0	1029.5	0-18	1029.5	1015.9	.9868	+ 23
6	6	576.0	586.0	0-02	586.0	574.9	.9811	— 34
7	6	736.0	748.0	0-03	748.0	734.9	.9825	— 20
8	6	804.0	814.8	0-04	814.8	802.9	.9854	+ 9
9	6	603.0	611.7	0-23	611.7	601.9	.9840	— 5
10	6	994.7	1011.7	1-16	1011.2	993.6	.9826	— 19
11	4	536.7	546.0	1-03	545.8	535.6	.9813	—0.0032
Means	.....	812.4	.....	.....	.....	.....	0.9845	0 0000

The probable error for the constant m is ±0.0005, or 1 in 2,000; the probable error for any course is ±0.0016, or 1 in 625.

Theoretically the wire interval, m, involves the nature of the country, the season, the working hours of the day, and the personal equation of the transitman; and this method seems to rest on a safer basis than the old way of fitting a rod graduation to the interval. However, after an interval factor has been established with adequate observations on a standard rod, a new specially graduated rod may be made in which the units are 1/m or the reciprocal of m, instead of a foot. The gain for this special rod holds only for approximately level shots on main transit lines; the loss lies in the fact that the rod has ceased to be a standard of measurement, that it is not interchangeable for other instruments, and in the extra work of graduation.

In applying the wire interval constant to the approximately level stadia readings a table was used made on a 3 x 5 inch index card.

The (c+f) correction is included in this table:

Table 2.—Subtractive Corrections for Side Shots up to 2°. For Gurley Instrument—June, 1901.

Distance in Hundred Feet.	DISTANCE AS READ. 00	10	20	30	40	50	60	70	80	90 ft.
	CORRECTION									
1	0	1	1	1	1	1	1	1	2	2
2	2	2	2	2	3	3	3	3	3	3
3	3	4	4	4	4	4	4	5	5	5
4	5	5	5	5	6	6	6	6	6	6
5	7	7	7	7	7	7	7	8	8	8
6	8	8	8	9	9	9	9	9	9	9
7	10	10	10	10	10	10	11	11	11	11
8	11	11	12	12	12	12	12	12	12	13
9	13	13	13	13	13	14	14	14	14	14
10	14	14	15	15	15	15	15	15	16	16
11	16	16	16	15	16	17	17	17	17	17
12	17	18	18	18	18	18	18	18	19	19
13	19	19	19	19	20	20	20	20	20	20
14	20	21	21	21	21	21	21	22	22	22
15	22	22	22	23	23	23	23	23	23	23

The correction for 1160 feet is —17.

The work of reduction is merely nominal using this table.

For reducing shots inclined at a greater angle than two degrees, the following table was used:

Table 3.—Subtractive Corrections for Each Hundred Feet of Reading Including Wire Interval Correction— Gurley—June, 1901.

MINUTES OF VERTICAL ANGLE.	DEGREES OF VERTICAL ANGLE. 1	2	3	4	5	6	7	8	9	10	11	12
0	1.58	1.67	1.82	2.03	2.30	2.62	3.02	3.46	3.96	4.52	5.13	5.80
10	1.59	1.69	1.86	2.07	2.35	2.68	3.09	3.54	4.05	4.62	5.24	5.92
20	1.60	1.72	1.89	2.11	2.40	2.75	3.16	3.62	4.14	4.72	5.35	6.04
30	1.62	1.74	1.91	2.15	2.46	2.81	3.23	3.70	4.23	4.82	5.46	6.16
40	1.63	1.77	1.95	2.20	2.50	2.88	3.30	3.78	4.33	4.93	5.58	6.29
50	1.65	1.79	1.98	2.25	2.56	2.95	3.38	3.87	4.43	5.03	5.69	6.40
60	1.67	1.82	2.03	2.30	2.62	3.02	3.46	3.96	4.52	5.13	5.80	6.53

(c+f)=1.1

This is part of Table V. of Johnsons Surveying, converted to include the wire interval factor, and changed from the form of a multiplier, to that of a difference. In using this the corrections corresponding to an observed angle are multiplied by the stadia reading, (using Crelles Rechentafeln in the multiplication) and this product [less (c+f) reduced for angle] is subtracted from the stadia reading.

One of these must be constructed for each instrument.

With the stadia readings reduced to level distance, the corresponding changes in elevation in carrying levels for contour work, were taken from the customary curve in which angles are

platted on radial lines, distance on horizontal, and difference in level on vertical lines of millimeter cross-section paper.

In reducing stadia surveys, the scale of the proposed map governs the refinement to be used. Whatever the scale, the readings of the lines of the transit circuits must be accurately reduced to check the latitudes and departures of the triangulation or base line system coördinating with the stadia system; but for side shots the severest necessary criterion is the working limit of the precision platting.

A thousandth of a foot may be taken as the working limit of the rapid platting of side shots. The field distances for different scales corresponding to this limit are as follows:—

Scale 1 in 30,000 allows distance of 30 feet.
" 1 in 20,000 allows distance of 20 feet.
" 1 in 10,000 allows distance of 10 feet.
" 300-ft. to 1-inch allows distance of 3.6 feet.
" 200-ft. to 1-inch allows distance of 2.4 feet.
" 100-ft. to 1-inch allows distance of 1.2 feet.

The field sheets of the St. Lawrence river work are platted on a scale of 1 to 10,000, and the final navigators charts are on a scale of 1 to 30,000. The greatest accuracy for the location of a point as regarded the final chart was therefore to the nearest thirty feet.

The accuracy of the transit circuits indicate a precision of 1 in 1120 for the American party, with 20 circuits averaging 16140 feet and 1 in 1400 for the Canadian party, with 23 circuits averaging 17050 feet each. In these is included the errors of observation, of interval factor, of azimuth due to converging meridians, and doubtless some mistakes in reading. The average length of course for the American party was 936, and for the Canadian party, 970 feet.

The accumulated residuals of one sign from the field work indicate the error of the interval factor for the Gurley instrument 1 in 2770, and for the Brandis, 1 in 950. This is very satisfactory for the former and unsatisfactory for the latter, a change of constant being necessary for final adjustment.

A remarkable feature of the Gurley instruments performance lies in the fact that the Canadian line run with it made many land and water crossing shots, following the ship canal. Such a line passing over both land and water is commonly considered a crooked one due to refraction when passing from air of one density over cold water to air of a less density over warm earth. Levelling under these conditions is rendered inaccurate, but the indications coming from this work are that the stadia distance is not invalidated, probably because the integrity of the rod intercept depends on

two lines of sight so nearly parallel that when one is bent by refraction the other is bent also and their divergence continues. It follows that the stadia measured distance is true over land and over water and over alternate field and river. It is probable that distances over water alone may be read more accurately than over land—especially on a hot July day when the air is boiling in baked meadows, and lies still over cool water stretches.

SOUNDING CATAMARAN WITH STADIA MAST.

The decision to use the stadia method in hydrography was strengthened by this accuracy of results as the topography was carried down the river. The steel whale-back catamaran, of 28 feet length, and 21 feet beam, which was used in the hydraulic work on the St. Lawrence was fitted with a stadia mast, consisting of a 3x3 inch square spruce scantling, 24 feet long, on which were nailed 21 foot-long galvanized iron hexagons, as shown in plates. This mast was pivoted top and bottom so as to face in any direction, and was held plumb by wire guys fitted with light turn-buckles. The accented zero mark was set about seven feet above the deck to allow a clear transit sight over the heads of the catamaran crew.

The catamaran was coupled at the bow of a tug and soundings taken on transverse lines, while angle and distance were read every minute by a transit man on the hydrographic station. Time for sounding and reading was signaled from the catamaran by the drop of a flag—either black, white, or red. Time and color of flag were set down by the transitman's recorder for angle and distance, and by the recorder on the catamaran for sounding—thus connecting the two.

How the sounding was done with heavy weight and wire and reel is another story beyond the limits of this paper.

It was something of a trick for the transitman to learn to keep his lower wire on the zero graduation of the stadia mast, and with the other hand swing the telescope in azimuth to follow the boat running as fast as five miles an hour, and read distance quickly at the drop of the flag, yet a little practice made it easy, and not more than one shot in a hundred was missed. Distance was read to the nearest ten feet, and angle was sufficiently accurate if the mast was five feet off the line of the cross-hair.

As the catamaran moved over the level water at a fair distance, the lower hair of the transit showed little travel along the mast, but remained near the zero when set there. By using the vertical slow-motion screw this was readily kept on zero.

In suggesting the use of the stadia on water, the question immediately arises whether wave motion will not keep the mast bobbing up and down and swaying back and forth, and make readings indeterminate or impossible. For a stadia rod in a skiff this would be true, but a vessel that is several times in length and beam the wave length shows at the axis of motion, very little rise and fall in a sea, and a catamaran especially shows very little or no roll. In the St. Lawrence work, the lift of the waves was rarely perceptible to the transitman. In a gale in a good stretch of river when a sea was running too heavy for work, the rise and fall as observed by transit, did not exceed a tenth of a foot, and the swaying of the mast was through but a few degrees, and did not interfere with reading.

The extreme radius of reading was taken at three quarters of a mile, using the upper half wire interval, while probably two thirds of the shots were within 2000 feet in which the full interval could be used.

The use of two transitmen saved the loss of time for the sounding party while either was moving to a new station, as one was always reading while the other was moving up to his advance station, and so the sounding went on continuously.

A test of the precision of long range stadia shots over water was made at the close of the season by anchoring the catamaran

rigidly in shallow water, at various distances; and reading in these distances both by the stadia and by triangulation. The triangulation from a carefully measured base line is considered as giving the actual distance.

Tests of Long Range Stadia Reading.

No.	Distances.		Differences	Dates 1901	REMARKS.
	Actual	Stadia			
1	2993	2983	+10	Nov. 20	Light not good. Air boiling.
2	4101	4099	+ 2	" 21	" good. " "
3	3746	3739	+ 7	" 21	" " Conditions fine.
4	1895	1898	— 3	" 21	" " " "
5	1086	1086	0	" 21	Bright sunshine. " "

The remarkable correspondence between the actual and stadia distances in (2) and (5) must be considered accidental.

In applying the stadia method to the location of soundings, its limitations must be clearly understood. It is not purposed to do away with locations by intersections, by range and transit, by sextant, or by time intervals, each of which has its place and use. But when the equipment is available, in a river not much over 3000 feet in width, it is plainly indicated as the most facile method, both for field and office. A single transitman, in this way, can do the work of two by the intersecting method, and one draughtsman platting angle and distance can do nearly twice the work done in platting from the crossing of two lines.

Topography, before the introduction of the stadia method, must have been a tedious process. We have changed all that by land, but there is no reason why the stadiaman should be limited by the shore line, except in the light of Peter's experience, lack of faith. On the St. Lawrence we had faith.

CEMENT TESTING.

FRANK H. CONSTANT, C. E.

Cement has come to play so important a part in modern structural work, forming the vital element of concrete and entering into nearly every piece of stone masonry as mortar, that no pains should be spared to insure the use of good cement. Hence, like steel, timber and other engineering materials, no considerable amount of cement should be allowed to go into a structure without being first subjected to certain tests which will make manifest its goodness or badness. What are the essential qualities that a cement should possess. These are, in the order of their importance:

(a) Soundness, or constancy of volume.
(b) Fineness.
(c) Strength.
(d) Activity, or power to set within a certain specified time.

(a) Soundness—

About sixty per cent of cement is lime, mostly in a combined state. Yet in the process of manufacture, by imperfect mixing of ingredients, or by insufficient burning, some of this lime may be present in a free state as quick lime. Often the free lime is in the form of minute but perfectly hard nodules, which do not slake immediately upon the introduction of water, but only after the lapse of some time and after the mortar has hardened in the structure. Slaking, which is always accompanied by expansion, may then be a destructive agency, causing a disintegration of the mortar and possible ruin of the structure. To test for unsoundness,—viz, the injurious presence of free lime—two round pats of neat cement, each having a diameter of about three inches, and being about ½inch thick in the center and tapering to a thin edge around the circumference, are made upon plates of glass. One of these is allowed to set and stand in air; the other, after hardening in air is placed in water. Both are kept for twenty-eight days. If, within that time, small cracks are observed upon the surface of either of the pats, the cement is unsound and should not be accepted in that condition.

It may be very desirable to hasten the action described above. The following simple test is often used. Place one of the freshly made pats in a moist, warm atmosphere of about 105° F. temper-

ature, for about four hours, or until it has set hard. An ordinary kitchen steamer and a cheap thermometer can be made to answer the purpose. After the cement has set, place it in the warm water and keep it at a temperature of 115° to 120° F. for the remainder of the twenty-four hours. If no cracks are noticed at the end of that time the cement may be safely declared sound.

A more severe test, used by the U. S. government, is to place the pot, after it has set hard, in boiling water for six hours. If no cracks develop in that time, the cement is certainly sound. But the presence of cracks is not in this case, to be taken as conclusive of unsoundness, and the twenty-eight day test is to be watched. Hence the boiling test is negative in character, conclusively showing whether a cement is sound, but not that it is necessarily bad. The warm water test is more positive and is to be recommended.

Unsoundness is often simply the result of the over freshness of cement. When this is the case it should be spread in thin layers on a dry floor for several days, to allow the free lime to be slaked by the action of the air. This treatment will often cause all symptoms of unsoundness to disappear and render the cement safe.

(b) Fineness—

Generally the finer a cement is ground the less danger there is from unsoundness, since the hard nodules of free lime are ground up and slake immediately upon the addition of water. This is the structural advantage of fineness. But there is likewise an economic advantage. Cement is always used, in mortar or in concrete, in conjunction with sand. Generally speaking it is only the fine, impalpable portion that has cementitious value, and which can bind the grains of sand together to form the hardened mortar. The coarser particles are more or less inert. Hence the finer it is ground the smaller the necessary proportion of cement to sand; or conversely, with a given proportion of cement and sand, the stronger will be the mortar.

Tests for Fineness.—A rough field test is to rub some of the cement between the fingers. It should be soft, greasy and impalpable to the touch, like flour. An appreciable amount of grit signifies coarse grindings.

For an exact test a special sieve is used, having 10,000 meshes to the square inch. The Government has adopted the following limit to the degree of coarseness. After sifting a small quantity of cement—say one or two pounds, for five or ten minutes, and weighing the residue, at least ninety-two per cent should pass through the sieve, with Portland, and at least eighty per cent. with Natural. The extent to which these percentages may be

reduced on work not governmental is evidently a matter of judgment on the part of the engineer, depending wholly upon the importance of the work and the exigencies of the case.

(c) Strength.—

Strength, the measure of the cohesion, is the one prime and necessary quality of all cement. White cement compounds are nearly always subjected to compressive strains, in structures, yet compressive tests are more difficult to make and require laboratory facilities and more elaborate apparatus than tensile tests, and as cohesion is just as surely tested by tensile tests, the latter have been universally adopted for the strength tests of cement. But of course tensile tests are purely comparative, and their value depends solely upon conformity, throughout the test, to generally accepted standard methods and results. For example, little else than a rough idea of the value of a cement would be obtained by making tensile tests upon bars six or seven inches long and having cross sections of two or three square inches when the standard briquette is but half as long, of peculiar shape, and has a cross section of one square inch. We know how many pounds the standard briquette, made of good cement, should carry in tension, but not how much resistance any other form of briquette should offer. In the latter case what may seem to us good cement may really be very bad.

Tensile Tests. Neat tests alone would answer, and these are always made, but since cement is always used with sand, briquettes containing a certain proportion of sand are also made. The usual proportions are, one to three for Portland and one to one for Natural, the proportion being by weight. Just enough water is used to give the thoroughly mixed mortar the consistency of damp sand. Another good rule is to add such an amount of water that the briquette may be removed without injury from the mold as soon as made, and yet such that a slightly greater amount of water would make this impossible. The proper amount of water will be from eighteen to twenty per cent for neat Portland; twenty eight to thirty per cent. for neat Natural; ten to twelve and one half per cent for one to three Portland; and fifteen to seventeen per cent. for one to one Natural. These percentages will vary slightly for different brands.

The brass moulds should be purchased from firms making a specialty of testing apparatus, for if not perfectly made in accordance with the recognized standard, slight inaccuracies will produce considerable variation in the results. For the same reason it is better to use one mold for all work. As a special machine is needed to break the briquettes, the tensile tests cannot be made in the field without a certain small amount of apparatus. An

automatic Fairbanks machine is compact and satisfactory, and costs, with mold, about one hundred dollars. Probably ten dollars more will supply all the needful equipment for a field testing laboratory.

Portland cement briquettes should be allowed to stand twenty-four hours in air, under a damp cloth, and the remainder of the time in water. Tests should not be made under three days, and preferably seven. Natural cement briquettes should stand in the air three or four hours, or until set hard, and should then be placed in water for the remainder of the time. Tests are sometimes made at the end of one day for neat briquettes, but not less than seven days for all briquettes is preferable. The Government requires that the developed tensile strength per square inch shall be as follows (and these values may be taken as representative of good average practice):

Portland—

Neat	7 days	450 lbs.
Neat	28 days	540 lbs.
1 to 3	7 days	140 lbs.
1 to 3	28 days	220 lbs

For quick setting Portland—

Neat	7 days	400 lbs.
Neat	28 days	480 lbs.
1 to 3	7 days	120 lbs.
1 to 3	28 days	180 lbs.

Natural—

Neat	7 days	90 lbs.
Neat	28 days	200 lbs.
1 to 1	7 days	60 lbs.
1 to 1	28 days	150 lbs.

The sand used should preferably be a crushed quartz sand, sifted to pass a standard sieve with twenty meshes per linear inch, and be retained on a standard sieve with thirty meshes to the inch. Clean sharp river sand, standardized in the manner just described, is sometimes used in place of the quartz.

It is of more importance that a cement show a material increase in strength with the age of the briquettes, than that it show a high initial strength with little or no subsequent improvement. Indeed such cements should be regarded with grave suspicion. There should be three or five briquettes for each test, and as many of the tests named in the above schedule should be made as the time will permit.

When the magnitude of the work is not great enough to justify the equipment of a small laboratory, a rough test of the strength of the cement may be made by breaking small pieces

of hardened mortar in the fingers or with a hammer, and by observing its behavior in the actual work. Often great strength is not required in the work and these crude tests may be sufficient. Yet, as a certain strength, developed in a standard briquette, is not only a sign of strength, but more particularly of the general all round goodness of the cement, the standard tests should be made if possible. The strength of cement could be determined in a simple manner in the field by a series of transverse tests. Wooden molds, making cement bars one square inch in cross section and about eighteen miles long can easily be made. These bars, placed across two supports, and loaded in the middle would by their resistance to the transverse load give a fair indication of the strength of the cement. This test will be more valuable if laboraory experimenters will make a series of transverse tests upon cements whose tensile strengths are known. Transverse tests, then, whenever made, could be interpreted into terms of tensile strength and thus be compared with the standards.

(d) Activity—

The engineer wishes his cement to set hard within a given time, and yet not to begin to harden before he has an opportunity to place it in the work. The two moments, then, in the time of total set, when the cement has just begun to visibly harden, and when it has set quite hard, are of considerable interest and worthy of careful note. They are called the times of initial and permanent set, respectively. To determine these two times in an accurate and standard manner, two weighted needles are employed. The first for initial set, has a diameter at the point of one twelfth of an inch, and weighs one-quarter of a pound. The other, to determine the set hard, has a diameter at the point of one twenty-fourth of an inch and weighs one pound. When these needles just cease to sink by their weight into a pat of mortar, the cement is said to have attained its initial and final sets respectively. These needles are easily made or may be purchased from dealers. The U. S. Government gives the following limits of time for these two periods:

Portland—

Initial set: Not less than 45 minutes.

Final set: Within ten hours.

Quick setting Portland—

Initial set: Not less than 20 minutes nor more than 30 minutes.

Final set: Not less than 45 minutes nor more than 2½ hours.

Natural—

Initial set: Not less than 20 minutes.

Final set: Within four hours.

The times of initial and final set may be determined very approximately without any apparatus, by simple inspection, pressure of the thumb nail, etc. Except for the practical necessities of the work this test is the least important of all.

In interpreting the above named tests for cement, it should be borne in mind that, at the last analysis, all that the buyer really wants is a *good* cement, and if he knew that he had this, he would be indifferent to its exact tensile strength, fineness or other qualities. But the term good is meaningless unless defined by qualities that may be found and compared. These tests, therefore, more or less arbitrarily chosen and standardized, are the means by which we define what is meant by good cement as distinguished from poor or bad. Other tests might have been devised which would have answered the purpose equally well, perhaps.

From this it follows that the judgment that a cement of which we previously know nothing is good and fit to be used, should be reached, not by a single test or tests for a single quality, suggestive as such test might be, but by making all of the standard tests and comparing the results one with another and with the standard limits.

For a small piece of work whose magnitude does not justify a laboratory equipment, the engineer should buy his cement from a well known manufacturer whose name and brand are sufficient guarantee for a generally good product. There are a number of such firms. But wherever possible the tests should not be dispensed with, since even the most reputable cement is liable to vary at times, or to be injured in the time between its manufacture and delivery to the purchaser.

While the tests are all simple in character, some little skill is needed in manipulation and interpretation of results, especially in making and handling results. Here the personal equation counts for a good deal. A little practice, however, brings the requisite experience and corresponding accuracy in results.

SOME EXPERIENCES IN MUNICIPAL CENTRAL STATION WORK.

H. A. HILDEBRANDT.

In all regular and well governed plants all the branches and departments should be under the direct observation and management of one person, and not be divided, as is often the case, but more especially in municipal plants, where each employee is favored by an alderman and often the superintendent has not the co-operation of the entire committee, where the line is placed under one person, the operation of machines under another, neither communicating to the other or to a third person, thereby never comparing results. This may be a crude condition of things, but such cases are in existence.

There is no branch of engineering which demands the wide range of experience and knowledge of central station practice. From the coal pile to the illuminant we have the conversion and transmission of the different energies to be performed in the most efficient manner under the conditions at hand. The actual practical experience is not enough to give the best results; a student who has completed a course in central station practice is always to be desired to manage such a plant, while he has not had the actual experience of the practical man, he is more often better equipped in knowing what the results should be and where the greatest losses are and their remedies.

The most important steps of conversion as to the best results in a plant are the first and last, depending entirely on the person in charge. The firing of coal and the selling and metering of current demand the undivided attention in a successful plant. All intermediate transformation of energies in an up to date plant cannot be made more efficient or improved upon by the person in attendance.

A good monthly allowance can be very easily lost at either the coal end or meter end, at the coal end the fireman has more bearing on the financial condition of the plant and as much responsibility as the engineer in charge of the machinery, but always put down on a lower position and under a smaller pay.

At the other end the metering and selling of current is always very interesting, because from the results of the meter you deal with man and his pocket book. The parting of man and his money is often more sad than humorous to him.

In making fall and winter month's collections you must have patience and perseverance as on patience your salary depends. As the nights grow longer the bills grow larger and your customer's howl grows louder. He will tell you the meter is wrong, that his bill is too large, that he is going to throw out the lights and the collector with them and put in gas lamps, etc.

Never fear his growl; it's worse than his bite. Quiet him by gentle means; tell him that the meter never over-registers but sometimes under registers, that the nights are a great deal longer than they were during the summer months when his bills were smaller; that half of the day's business is done through the help of the lights.

Never express a doubt as to the accuracy of the meter; if you do you will get yourself into no end of trouble. If you take down your customer's meter to test to humor him or to satisfy him in regard to a bill, you will have the same testing to do at very frequent intervals, and others will also want to be humored the same way, and you might as well start a meter testing department.

Never express the slightest idea that the meter will over register, but always keep a close watch that they do not under register. Your customers are many, and among them you will find all kinds of characters, good, bad and indifferent, on which very often depends the condition of the meter.

You should keep an eye on the amount of illumination the different places have; compare their bills and if satisfactory results are not had make mid-monthly visits to the meter; it might prove profitable.

A very satisfactory result was obtained by such a visit one evening after the lights were on. Thinking the meter was very peculiar, as it worked well when tested at the station but never brought in the income it should, I decided to test it in position by means of incandescent lamps. I didn't understand the connection at first as there were five wires entering the meter from the bottom, and old type I. H. meter. Upon close investigation found that the one wire was short and was of mechanical rather than electrical purpose, forming a brake on the disk. After removing the wire the meter did much better work.

Another meter was found with a very handy shunt wire easily removed and replaced. As the trick grew older the customers grew bolder, and thereby "killed the hen that laid the golden eggs."

Every plant on the meter basis with a reasonable meter rate for the long winter nights must have a minimum monthly meter charge to make a success of electric lighting. Most private plants

have, but municipal plants have not, and therefore are not making the success they should.

The results of two municipal plants are very interesting. During the summer months the meters were not read monthly, as the readings were too small to collect; so the readings were not taken for intervals of three and four months. Collections in these places have amounted to 15 cents and 30 cents for three months' use of electric lights, while the station carries the meter load, transformance capacity and dynamo capacity to light every lamp in any house at any time. This loss to the station is made up by the taxpayer, who doesn't know it. One of the above stations according to the report, is making money. They include in operating charges interest which they are still paying on $6,000 which they still owe on plant, and do not charge any depreciation on machinery.

THE APPLICATION OF A TECHNICAL EDUCATION

By O. P. Briggs.

Were every honest, energetic graduate of our Universities or high schools asked the question, What subject was occupying his mind most, and to the exclusion of nearly all others, immediately after his graduation, ninety-nine out of one hundred replies would be, "How am I to get a living?"

At this time it really begins to dawn on him, as never before, that he has now to face the real problem of life, "Where is my bread and butter to come from. Where shall I find shelter and clothing?" to say nothing about the luxuries of life that are always to be enjoyed if acquired honestly.

This date marks the beginning of his career and often times the turning point, when he is thrown squarely on the world, dependent upon his own individual resources.

"He who by the plow would thrive himself must either hold or drive," one of Benjamin Franklin's wise sayings, applies to all professions, occupations or callings, and in no place is this more applicable than to the college graduate.

There has been a tendency among colleges to allow the idea to creep in on their students that a college certificate of graduation would be a through ticket for life, including stop over check, sleepers, dining car service and sundries. This is the most disastrous idea that ever entered a student's mind.

The graduate who fosters the idea that his education will provide him with the necessities of life, and carry him through safely, without work, hard work, and a diligent application of his knowledge to the calling he has chosen, is to be pitied.

One of the saddest situations I ever witnessed was out in a western town during the hard times of '94 and '95 where a number of graduates of eastern colleges had undertaken to open up a new territory. Not one in the lot knew how to turn his hand to any kind of manual labor, not even the simplest. They could no more harness a horse, plow a field, saw a cord of wood, or even go to market than the boy six years old. They were utterly helpless and when the short crops and hard times struck them the result was most disastrous. Unhappy, poor, discontented, soured on the world generally, and a thousand times worse off than the roughest cowboy in the country, who signs his name with a cross. A clear case of Prof. Zeublin's "Social Machine out of joint." The only ones among them who were enjoying life at all or who could see any good whatever in this world, were the

few who had the sand and pluck to ride a bronco and take their chances on the plains with the cowboys, drawing the same pay and sharing with them the same accommodations.

Well do I remember the remarks of a good old down east country school teacher who made a success of teaching school, fall, winter and spring, and who was equally as successful farming among the rocks and hills of that rough New England country.

He fully realized the advantages of an education, for he acquired what he had under very adverse circumtsances. On the "last day of school occasions" the prevailing custom was for the teacher to consume the greater portion of the afternoon in giving advice to the students. This custom he pursued to some extent, and after having urged upon them the importance of a good school education and advising them to pursue their studies during the vacation, and return to school at the earliest possible date, he invariably wound up his remarks with this caution, "But don't forget that of all the education you can acquire, in school or out, the most useful part of it is that portion which teaches you what a dollar costs produced by the sweat of your brow."

Rail at the "almighty dollar" all you may, the fact still remains that without the ability, knowledge, trade or skill necessary to earn it one is on very dangerous ground. The all important point in deciding one's occupation is, What am I best fitted for.

In the mechanical world, in which branch of mechanics can I best succeed, and in measuring this element, success, the two prominent points are, which branch will yield me the greatest revenue and at the same time the most pleasure. It must be conceded I think that a man who is naturally a mechanic will derive a vast amount of pleasure while pursuing this trade if he succeeds, for the successful man in all branches of trade, in all the professions and in all lines of mechanics is the man whose heart and soul are in his work and who makes a study of his calling a pastime rather than a duty.

The best education one can acquire then is, such as will enable him to so intelligently apply his natural talent and qualifications as to bring him the greatest returns both materially and socially. Such as will enable him to make the most of this life.

Could every student of our land determine during his school life what his occupation was to be, he would find it a very great advantage.

I hope I may be pardoned for saying right here, that while our schools are the just pride of our people, while in the school house is laid the very foundation of this government, and while we shall not over do it in saying all the complimentary things we

can think about them, there is still a chance for improvement, just as there is in all other branches of our social life. I am convinced that a greater effort should be made through the last two or three years of a student's life to enable him to select his calling.

Unless one is engaged in some kind of business, it is almost impossible for him to realize at what a terrific pace this commercial and mechanical world has been moving during the past few years. It is beyond comprehension, and in my judgment the typical young American, found here in such numbers, should be educated more in conformity to these rapidly changing conditions. Our school system should be kept in the very closest touch with the business world that the student at the close of his school life may be prepared to go out into the world and earn a living at least as easily as his neighbor is earning it who perhaps has never attended school at all.

Here in the State of Minnesota we have as good mechanical blood as the world has ever seen. Now why not educate these natural born mechanics and turn them on the world as good as can be produced? If naturally mechanics they will certainly get more out of life following such pursuit than in any other calling.

This choosing one's occupation applies all along the line from the grammar school to the college. If you are deeply interested in and successful at the study of electricity don't think of educating yourself to preach the gospel. Let the boy who loves history and the Bible have that field to work in. He will succeed; you will not. The mechanical world, like nearly all other branches, moves by specialties, hence it is to the student's advantage to select that branch of the trade he prefers to follow while still in college, that he may better prepare himself to take up his life work promptly. In this age of rapid development along these lines there is always an opportunity for the technically educated young mechanic provided he is willing to work and work hard, work with his hands as well as his head. Even the journeyman mechanic who pursues this calling accomplishes more, gets greater returns for his labor (besides having always in view the possibility if not the probability of advancement) if this work is directed by a well developed and technically trained mind.

This is the direction in which the mechanical mind is moving today and fortunate the young man with a technical education who is willing to put on his overalls, learn a trade, take his place in the ranks and put his theory into actual practice with his own hand. Such boys are always in demand and after having once shown themselves are never out of employment.

The successful employer of men is ever on the alert for the skilled hand directed by a trained mind.

BREAKWATERS AND PLANS FOR BREAKWATER EXTENSION AT AGATE BAY, TWO HARBORS, MINN.

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[Read before the Club, November 18, 1901.*]

A BREAKWATER is a structure built for the purpose of breaking the force of the waves entering a harbor or anchorage. Breakwaters are usually built to protect the mouth of a natural harbor, but also for the making of an entirely artificial harbor or anchorage.

EXAMPLES IN EARLY HISTORY.

Breakwaters, for the purpose of protecting harbors, are of very ancient origin. The harbor of Alexandria was protected by a stone mole called from its length, the Heptastadium, or seven-furlong mole, which joined the island of Pharos and the mainland. It was probably commenced soon after the founding of the city, 332 B. C. It was pierced by two passages, which were spanned by bridges. It was probably built of rubble or riprap stone. An accumulation of alluvial deposits about it formed a broad neck of land, upon which the greater part of the present city of Alexandria is situated.

Herodotus states that Nebuchadnezzar built quays and breakwaters along the shores of the Persian Gulf. This would be between 604 and 562 B. C.

The harbor of Rhodes and the Piræus of Athens were protected by moles, as were also those of many cities among the Romans. The Romans constructed the moles or breakwaters of many of their harbors upon a double row of arches, so arranged that the openings of one set were opposite the piers of the other. This construction thoroughly broke the force of the waves, while still permitting the passage of the current, thus greatly reducing the accumulation of deposits around the base of the structure and the consequent tendency toward filling up the harbor.

We are informed by Josephus that Herod, desiring to form a port on the coast of Syria, between Joppa and Dora, caused great stones, most of them 50 feet long by 10 feet wide and 9 feet deep and some even larger, to be cast into the sea in 20 fathoms of

* Manuscript received January 18, 1902.—Secretary, Ass'n of Eng. Socs.

water, with a view of forming a foundation for a mole or breakwater.

The resistance to be exerted by a breakwater is primarily that caused by the movement of water in waves.

RESISTANCE TO BE OVERCOME.

The force exerted by the waves is very great; and, as was said by Smeaton in connection with the construction of the Eddystone Lighthouse, "is a power of nature that is subject to no calculation."

Observation and experience furnish some data from which deductions may be made. Attempts have been made to measure the force of waves by means of the marine dynamometer, which consists essentially of a flat disk on which the waves impinge directly. These disks are from 6 to 9 inches in diameter, and are connected by rods with a strong spring inclosed in a cylinder, so that the stretching or drawing out of the spring can be determined, and from this the force of the waves can be measured or calculated. The force determined in this manner varied from 1.5 tons per square foot in the German Ocean to 3.5 tons in the more exposed parts of the Atlantic.

The work done by the waves in the destruction of breakwaters and lighthouses tends to confirm these experiments.

The most remarkable instances of wave power were observed at Wick Bay Breakwater. In 1872 a solid mass of masonry, 45 feet wide, 26 feet long and 21 feet high, weighing 1350 tons, was turned round upon its base and finally tilted off its foundation, and the following year at the same place a mass weighing about 2600 tons was moved in like manner.

The maximum height of waves which strike breakwaters in the North Atlantic is variously given as between 22 and 40 feet. Heights of waves as great as 60 to 108 feet above the hollow have been reported; but 50 feet is probably the maximum.

It has been found that the height of waves varies, in different localities, as the square root of the distance from the windward shore. From this the formula has been deduced $h = a\sqrt{d}$, in which h = height of wave in feet, d = distance of length of fetch in miles, and is a coefficient varying with the strength of the wind. a = 1.5 is used for heavy gales in deep water. In short fetches waves are raised higher than given by this formula. Long fetches, as the distance across the ocean, would be limited by the distance through which the gale was blowing.

This formula was deduced from observations upon the European coast of the Atlantic. In 1884 Mr. Wm. Pierson Judson, C. E., made some observations upon Lake Ontario at Oswego

N. Y. During a severe northwest gale, the waves, at a distance of 1000 feet outside the breakwater, attained a height of from 14 to 18 feet. The fetch from this direction is about 80 miles, and the formula would give a wave height of 13.5 feet.

I know of no accurate experiments having been made upon Lake Superior. A Government report upon Eagle Harbor, Mich., gives the maximum height of waves upon Lake Superior as 10 to 12 feet. I have observed waves which appear to be 10 or 12 feet high with a southwest gale at Grand Marais, Minn. Here the fetch is about 64 miles. The formula gives a height of wave of 12 feet. At Two Harbors, Minn., the fetch from the southwest is about 30 miles, for which the formula gives a height of about 8 feet. This is somewhat higher than I have observed, but I was told of storms which I judge reached this height.

The greater number of severe storms at Two Harbors come from the northeast. The fetch from Isle Royal is about 120 miles, for which the formula would give a height of about 16 feet. I doubt whether the waves there ever go higher than 10 feet. The wind blows nearly parallel with the shore line, and the friction of the shore interferes with the free movement of the wave form.

It is generally stated that waves break when they reach a depth of water equal to their height, but they sometimes break in water of twice that depth.

"On the assumption that, at the instant of breaking, the vertical section of a wave at the surface is a common cycloid, and the height, h, of the wave is not greater than the depth of water in which it moves, theoretical energy, in foot-pounds per linear foot of the wave crest $=\frac{64\pi d^3}{32}=2\pi d^3$; the weight of a cubic foot of sea water being taken at 64 pounds."* "For wave depths of 10 feet, this gives an energy of 6300 foot-pounds, and, for wave depths of 15 feet, about 21,000 foot-pounds. If the form of the wave, at the moment of breaking, is that of a prolate cycloid, as some authorities assert, its energy would be about 60 per cent. greater than that above stated. While such calculations are more curious than valuable, they nevertheless serve to convey some idea of the force impressed upon breakwaters by wave action."†

MANNER OF DESTRUCTION.

The destruction of a breakwater, or of any portion of one, is in many instances caused by the undermining of the foundation. The force of the waves is exerted to a considerable depth, especially when given direction by a vertical faced wall. Hence, where

* Report Chief of Engineers, 1889, p. 1321.

† Papers by Louis Y. Schermerhorn, Mem. Am. Soc. C. E. in *Eng. News*, Aug. 25, 1898.

a breakwater is founded upon a natural bottom of loose material or upon a mound of rubble stone, it should be protected by placing large stones or blocks of concrete on the exposed surface.

In some cases blocks of masonry have been torn out of the exposed face of a solid wall, and the disintegration of the breakwater started in this manner. In other cases, as in that of Wick, previously mentioned, a large portion of the superstructure may be moved and overturned.

The force exerted by the waves is greatest when the waves strike at right angles to the line of the breakwater; hence, where possible, the line of the breakwater should be placed at an angle oblique to the direction of the prevailing heavy storms.

RESISTANCE TO ICE.

In some localities breakwaters are subject to the action of ice. The force exerted by ice is greatest in the mouth of a river, where large fields of ice break loose and are given quite a high velocity by the current. At Delaware Breakwater, near the mouth of Delaware Bay, the ice fields come so that they would strike against the inside of the main breakwater. To protect the shipping, which might be seeking shelter from ocean storms, a secondary break-water had to be built as a barrier against ice.

The pressure exerted by ice cannot be greater than its resistance to crushing.

For computing the necessary strength of the Delaware ice barrier, the formula was deduced: $u = \frac{1}{2} \frac{W}{g} V^2$. The greatest distance that a squeeze can be transmitted through ice is 1200 feet, as the ice crushes and the residual force is exerted in breaking it up. 1200 can then be used as the modulus of cohesion of ice under compression. Then, with b representing the breadth of a field of ice, d the depth and the weight per cubic foot of ice being taken = 57.4 pounds, $W = (1200 \times b \times d)\ 57.4$. $g = 32.2$. Substituting in the formula the greatest possible effect of a field of ice $= u = \frac{(1200 \times bd)\ 57.4}{64.4} V$, the velocity of V being that which the field of ice has acquired at the moment of impact.

Ice would not hold together with a high velocity, else in some cases it might obtain such a momentum as to be almost irresistible.

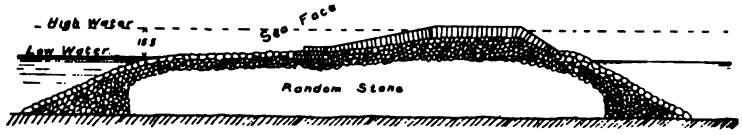
Upon Delaware Bay and in similar localities ice probably attains the velocity of one mile per hour and remains intact. Upon Lake Superior, before attaining that velocity, it would be broken up so as not to act as a solid mass; but, for the sake of seeing what effect it might have, we will calculate with reference to the breakwater designed for Agate Bay. Assume a wide

expanse of ice 1.5 feet thick, with a solid breadth of 600 feet, to strike against 410 linear feet of 24 x 24 ½-foot timber crib breakwater. Then b = 600 feet, d = 1.5 feet, and, at one mile per hour, V = 1.47 feet per second, which, supplied in the formula, gives $u = \frac{1200 \times 600 \times 1.5 \times 57.4 \times 2.16}{64.4} = 2{,}080{,}000$ foot-pounds of energy = W′ S, W being the weight of the obstruction and S = the distance through which it is moved.

In this case W′ = about 13,200,000 pounds, which gives S = 1⅞ inches. The breakwater might possibly stand a very few blows of that kind, but not many.

MODERN METHODS OF CONSTRUCTION, WITH EXAMPLES IN FOREIGN COUNTRIES.

There are two general forms of construction, one with long sloping faces, the other with vertical or nearly vertical face. Then there is a form which is a combination of these two.



Section of Breakwater at Plymouth, England.

FIG. 1.

The long sloping-faced form is built of riprap or loose rubble or random stone, sometimes called "pierre purdue." It may have a core of gravel, sand or earth if at such a depth as not to be washed away either during or after construction.

The long sloping-faced form is called the "primitive-form" in a recent article by an English engineer, and is very little used in recent construction in Europe and Asia.

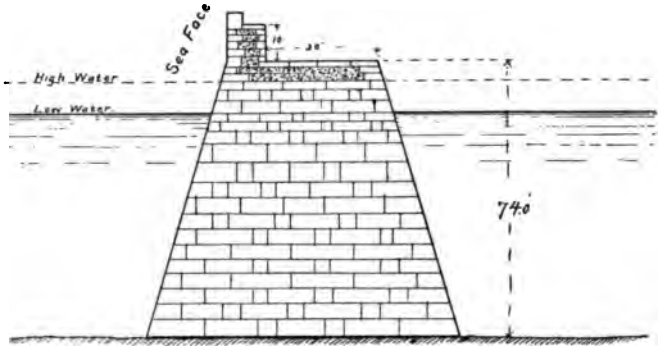
A very good example of this form is found in the breakwater at Plymouth, England. It was commenced in 1812 and completed in 1841, and hence is one of the oldest of modern construction. It is situated upon the inner one of three natural reefs of rock, which lie outside the harbor, and closes what was once a natural passage, leaving open passages to the east and west. The main body is placed perpendicularly to the south-southeast, and is 3000 feet long. Wings at each end form angles of 135 degrees, and are each 1050 feet in length. It protects a surface of 1120 acres.

A sectional view is shown in Fig. 1.

The breakwater is built entirely of riprap, except that the greater part above low water is revetted with masonry laid in Roman cement. 4,105,900 tons of stone were used in its con-

struction, and cost $7,500,000. The slopes, which were largely governed by the action of the waves, are about as here shown. This form of breakwater allows the water to roll over it, but the wave is so completely broken as to disturb the tranquility of the harbor but very little.

Vertical-faced breakwaters cause the waves to be reflected back seawards. They require a very solid superstructure and foundation carried to at least twice the depth of the waves below low water, to prevent being undermined. Or the base may be protected by large blocks of stone or concrete in the form of rip-rap. They are built of solid stone masonry or concrete. The breakwater at Dover, England, a section of which is shown in Fig. 2, is a good example of solid ashlar masonry.



Section of Breakwater at Dover, England

FIG. 2.

This was of very slow and difficult construction, the greater part of the work having to be done by divers under water. In more recent undertakings in Europe and Asia the wall is usually built entirely or mainly of concrete.

One method of concrete construction is by building the under water portion by depositing the concrete in sacks. The sacks prevent the concrete from disintegrating before it sets, and, when it is set, it conforms in shape to its foundation.

The breakwater for the harbor of La Guayra, Venezuela, was built in this manner. A section is shown in Fig. 3.

The sacks in the lower tiers were 48 feet long, but, when deposited, they stretched to 54 feet, and other lengths stretched in the same manner. Many of the sack blocks weighed 160 tons. The blocks extending to water surface weighed 70 tons. The lower blocks were deposited from hopper barges, the upper ones from large tippers run out on six lines of rails. Upon the top of the substructure thus built concrete in mass was built in sections of 40 feet length, each section requiring one and three fourths to two days to complete.

In the greater number of breakwaters situated in deep water the foundation is of loose rubble or riprap stone, and has a vertical-faced superstructure. The base of the solid superstructure varies, in different designs, between high-water level and 44 feet below low water.

A design which has met with considerable favor, and has been used in a number of places in Europe and Asia, has massive blocks of concrete sloping in the direction of length of the breakwater, these so placed that each section of blocks may set-

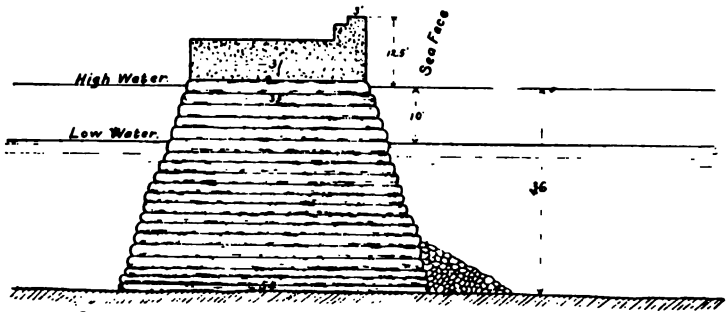


FIG. 3.

tle independently; but the blocks in the sections are well tied together. The top of the concrete block structure varies between low-water level and several feet above high water, and in several cases is topped with concrete in mass after settlement has ceased. A good example is the breakwater at Colombo, Ceylon, Fig. 4.

At this place a wall 24 feet wide, but otherwise of the same design, was moved 15 inches at the outer end by a heavy storm.

The most renowned example of the composite type of breakwater is that at Cherbourg, France, Fig. 5. It represents that form of the composite in which the riprap embankment comes above low water. It was commenced in 1784 and finished in 1853. It is about 3 miles long and cost about $12,500,000.

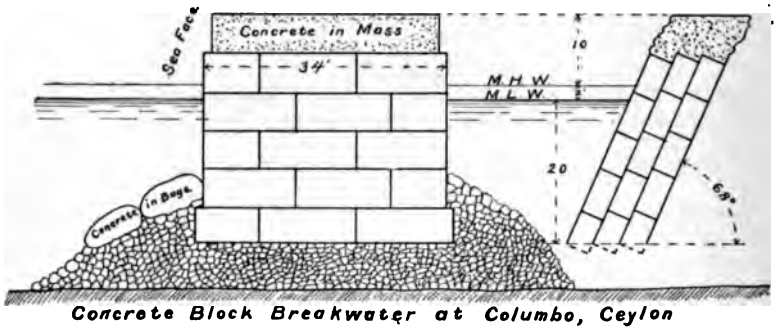
The wall starts at low water, with a bed of hydraulic concrete 5 feet thick, and upon this was erected a solid wall of coursed ashlar masonry faced with granite. The top of the sea slope is covered with large loose blocks, and at the extremities of the wings it is further protected by immense blocks of concrete weighing about 40 tons each, forming a rubble set in hydraulic cement.

A number of ingenious designs in concrete construction, especially adapted to the places for which they are designed, have been built in Europe in late years.

SEACOAST PRACTICE IN THE UNITED STATES.

Upon the seacoast of the United States the universal practice is to build breakwaters of rip-rap or random stone. This is principally due to the fact that near their locations good stone is cheaply obtained, making this the most economical method of construction.

The first breakwater built in the United States, and the only one for some time, was the Delaware Breakwater at Lewes, Del., just inside the mouth of Delaware Bay. It was built for a harbor of refuge for vessels passing along the coast. It was started in 1828. Although it has an anchorage area of 420 acres between 3 and 6 fathoms deep, its capacity has been fully utilized during storms, and an additional breakwater is now being built 2.5 miles north, with an area of 562 acres, having a minimum depth of 30 feet, and 237 acres additional between 30



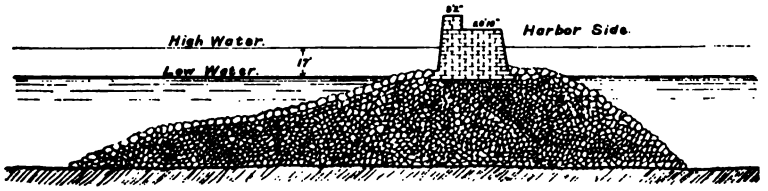
Concrete Block Breakwater at Columbo, Ceylon

FIG. 4.

and 24 feet deep. The original Delaware Breakwater consisted of the breakwater proper, 2558 feet long, an ice breaker 1359 feet long, to protect the harbor thus formed from ice brought down by the Delaware River. Between these was a passage 1390 feet wide. This gap was closed several years ago, to give additional anchorage room and security. The total cost of these 5307 feet of breakwater was about $3,000,000. An average cross-section of Old Delaware Breakwater is shown in Fig. 6.

The embankment was made of less width than those of similar construction in Europe, the sea face slope in several cases of European construction being as flat as 1 vertical to 7 or 8 horizontal between high-water line, and 10 or 12 feet below low water, or on part of this distance. In some cases level benches divided the slope, making a foreshore of extra width for the waves to break upon. The slopes in Delaware Breakwater are very nearly those given by the action of the waves. The waves are higher where most of the European breakwaters are situated, but the difference in slope seems greater than should be

required. The slope is also determined by the size of stones used. The ordinary sizes of rock used, ranging usually from 40 to 2000 pounds in weight, will stand at a slope of 1 vertical to 1.5 horizontal up to about 12 feet below low-water line, with waves as on the American coast. This depth marks what is called the plane of rest, or limit of energetic wave action. The depth of the plane of rest varies, of course, with the energy of the waves and with the size and character of stone used. Above the plane of rest much flatter slopes must be used. By protecting the surface of the slope with the largest stone that can be economically handled, the steepness of the slopes needed may be increased. By using surface stones above 3 tons in weight, the average slope between high-water level and the plane of rest is increased to 1 to 3 in American practice.



Section of Breakwater at Cherbourg, France.

FIG. 5.

The superstructure, or part above high-water level, in the most recent types of American random stone breakwaters, consists of rough, strong walls upon the sea and harbor faces of the work, built of larger stone systematically placed, so as to secure a strong bond; the space between these walls being filled with stone varying in size, so as to form a compact mass. The placing of these large stones requires the use of very powerful derricks. The sea slopes of superstructures built in this manner vary between 1 to 0.7 and 1 to 1. Otherwise the cross-section of the recent designs of American coast breakwaters is in most cases nearly the same as in the Old Delaware Breakwater. Old Delaware Breakwater was under construction from 1828 to 1840 and from 1866 to 1869, and the gap was closed during the years 1883 to 1899. Separate contracts were let under each appropriation of Congress. The average cost per ton of rock for the first two periods was $2.50, for the last $2.30.

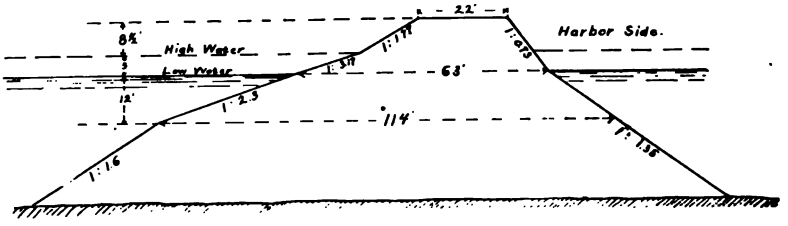
The more recent projects have been let by continuous contract, or by one contract to cover the entire construction, but paid by several appropriations, the number varying with the time required. This results in a great saving, as the contractor is warranted in investing in a working plant adequate to handle the work most economically. The New Delaware Breakwater

was thus let at $1.18½ per ton, a saving of about 50 per cent. over former prices.

CONDITIONS ON THE GREAT LAKES.

The conditions on the Great Lakes differ from those on the ocean, mainly in that the waves do not attain so great a size and that the water is fresh instead of salt.

The waves being smaller, a less massive construction of breakwater is required; but the principal difference between the usual manner of construction upon the Great Lakes and that upon the ocean is due to the fact that timber may be used in fresh water for permanent work, while in salt water it cannot, owing to its being destroyed by marine worms. Timber when kept constantly under fresh water will last for an indefinite time,



Average Section of Old Delaware Breakwater

FIG. 6.

and seems not to deteriorate or lose any of its strength. Adding to this the fact that the Great Lakes were surrounded by immense forests of pine, hemlock, etc., making timber very cheap, we have conditions which make timber cribs, filled with rock, the most economical method of stable construction of breakwaters.

The rock is held in the form of a solid wall by the crib at a considerably less expense than would be required for a solid wall constructed in any other manner.

A random stone breakwater would require so much more stone as to make it much more expensive.

COMPARISON OF COST OF DIFFERENT METHODS OF CONSTRUCTION.

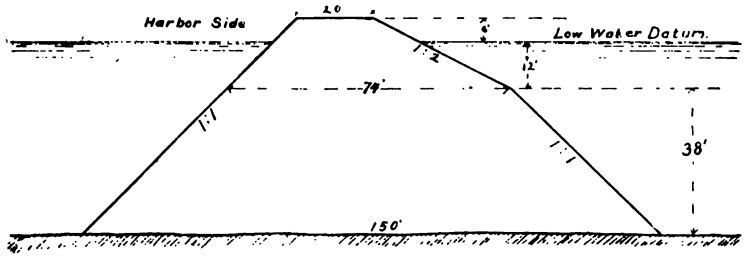
We will now make a comparison of cost of some different methods of construction which might be used for the Agate Bay Breakwaters.

We will figure for a depth of 50 feet below low-water datum, as this is nearly the average depth of the Agate Bay Breakwater extensions.

First. A random stone breakwater of the form recently built at Point Judith, R. I., a section of which is shown in Fig. 7.

This is probably as economical a section as would retain its stability at this location, and would require that, below 12 feet below datum, the plane of rest, the slopes be covered with stones weighing from 1 to 5 tons, and that, above the plane of rest, the slopes and top be covered with stones weighing from 3 to 10 tons, and the upper ten feet be systematically laid so as to secure a strong bond. This section contains 5102 cubic feet per running foot of breakwater. 5102 cubic feet equal 39.86 cords of rock. 39.86 cords, at $6.50 per cord, equals $259.09 per running or linear foot of breakwater.

Second. A breakwater with random stone foundation, concrete blocks from —6 to + 1 and capped with concrete in mass to +6. Concrete structure 20 feet wide, built as at Colombo Ceylon (Fig. 4.). Width of random stone embankment at — 16 to be 40 feet. Slopes 1 to 1.5, extending up to the side of con-



Section of Point Judith, R.I., Breakwater, except 4' lower for Lake Superior

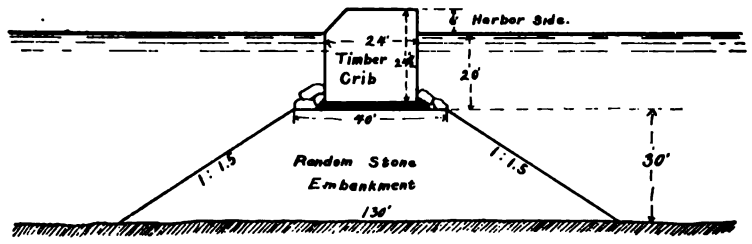
FIG. 7.

crete. The riprap at the sides of the concrete to be of stones exceeding 3 tons in weight. Cross-section area of rock embankment and riprap equals 3160.7 square feet. 3160.7 cubic feet equal 24.77 cords of rock per linear foot. 24.77 cords, at $6, equal $148.62. 452 cubic feet equal 16.74 cubic yards of concrete per linear foot. 16.74 cubic yards, at $6.50, equals $108. 81. Total cost per linear foot, $257.43.

Third. The form of breakwater adopted was composed of timber cribs and superstructure upon a random stone or riprap embankment. Cross-section, for 50-foot depth of water. (Fig. 8.)

Stone embankment to 20 feet below datum measures 2550 cubic feet = 19.92 cords, per linear foot. 1992 cords at $6, cost $119.52 per linear foot. Crib and superstructure, all above elevation—20, $75.30 per linear foot. Total, $194.82 per linear foot.

This is $63.61, or nearly 33 per cent. less than the probable cost by other methods. This would amount to $25,440 for 400 feet. Without stopping to calculate for the various depths, either of the first two methods would probably cost about $100,000



Section of Breakwater built at Two Harbors, Minn.

FIG. 8.

more for the total 1960 linear feet than the $240,000, which the third method will cost.

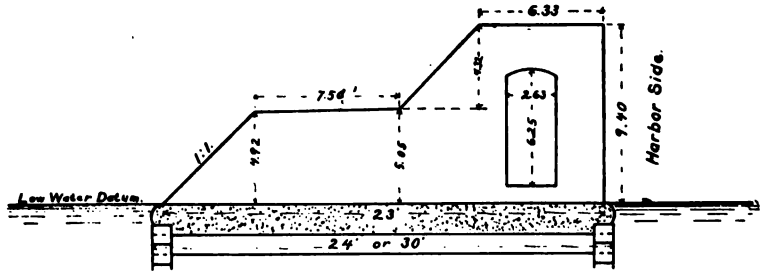
REBUILDING OF SUPERSTRUCTURE OF TIMBER CRIBS.

The superstructure, or that part of the breakwater above low-water datum, will, in about 20 years, have its timber work rotted so as to impair the strength. This could be replaced for probably about the original cost of the superstructure, $20 per linear foot; but if a permanent structure is desired, it would be better to rebuild the superstructure of concrete.

In a case of this kind it is better not to build the concrete superstructure at first, as the structure is subject to settlement. The timber superstructure being more elastic than the concrete, it is not seriously injured by a considerable amount of settlement; while the concrete would be. Before the superstructure needs replacing, the cribs will most likely have reached an unyielding position. If not, they can in nearly all cases be made to do so by more riprapping. A very good design for concrete superstructure is that which has been placed upon part of the timber crib breakwater at Marquette Harbor, Lake Superior, and will be placed upon the remainder as soon as possible after the money has been appropriated by Congress. A cross-section of it is as shown in Fig. 9.

The timber work is removed to one foot or a little more below low-water datum, and the stone filling made compact over the top. Upon this Portland cement concrete is laid up to datum, it being held in place by burlap before setting. The part above datum is built of natural cement concrete in lengths of 10 feet.

The cost per linear foot of blocks was $20.48; of blocks and footing, $30.10; with all accessory work, which includes the removing of timber and stone, $41.88 per linear foot. To finish in this way there would be a saving of only 12 to 15 per cent., in addition to the interest on the money, over what a permanent structure would cost.



Concrete Superstructure on Timber Crib at Marquette, Mich

FIG. 9.

To obtain the figures given for a permanent structure, however, it would have undoubtedly to be let in one or a very few large contracts, which would require more money at once than Congress has heretofore been willing to appropriate for a harbor of this class.

GENERAL PRINCIPLES OF TIMBER CRIB CONSTRUCTION.

The first great crib breakwater was built at Buffalo, N. Y. Before deciding on the design to be followed, the Advisory Board of United States Engineers of 1853, formulated some general principles to be followed in the construction of timber crib breakwaters. These are regarded practically as axioms.

They are as follows:

"The cross-section of the foundation cribs should fill certain practicable condition. They should be:

"First. Of such figures as to throw the common centre of gravity of the foundation and superstructure low down.

"Second. Of such lines for its sides as will enable us with simplicity and effectually to tie the superstructure down to its foundation, so as to make the under and above water parts inseparable by the action of a force against the mass.

"Third. Such that the crib can be easily floated, in a position of stable equilibrium, from the place where it is framed, out of the harbor, and sunk where it is to stand. This implies symmetry of parts on both sides of the vertical line passing through the common centre of gravity.

"Fourth. The walls of the crib constituting the foundation should rest in such a manner, in regard to angle with the horizon, that the weight of the walls of the superstructure may be as much as possible transmitted directly to the walls of the crib, and not bear upon its cross-ties at points within its walls. Again, the walls should rise in such manner that the rubble stone filling, which must be thrown or dropped in, will assume a position bearing well against the sides of the walls.

"Fifth. The width of the base of the foundation should not be unnecessarily large, for it would require splicing of ties and and bottom timbers to make them long enough, which would be very expensive and produce unnecessary cost of construction."

These conditions are best met when the crib and superstructure have a square (or very nearly square) cross-section. This being the case, the timber crib work can be economically built only to a limited depth.

ECONOMIC PROPORTIONS OF CRIB AND RIPRAP EMBANKMENT.

The usual plan in constructing this style of breakwater in deep water is to have the lower part of foundation composed of riprap or random stone embankment. To determine the proper relative proportions, considering the cost of the work, Mr. J. H. Darling, First Assistant Engineer at the Duluth office of United States Engineers, deduced the following formula. See Fig. 10.

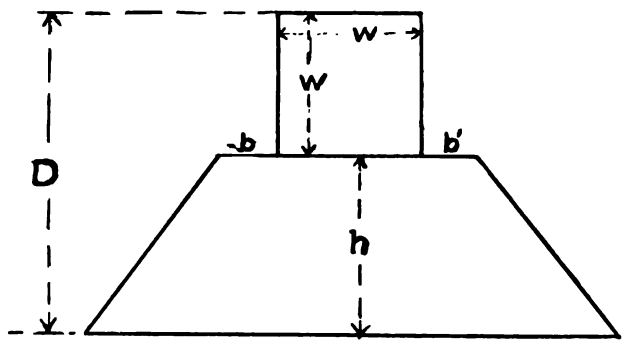


FIG. 10.

D = Depth of breakwater.

h = Height of embankment.

W = Width and depth of timber pier.

B'' = Sum of berms b and b'.

S = Ratio of slope, base of vertical.

R = Ratio of cost of timber pier to embankment for equal volumes.

U = Cost of linear foot of breakwater in terms of a cubic foot of embankment.

Then $U = R W^2 + h (W + B'' + S h)$

As $h = D - w$

$U = R W^2 + (D - W) (W + B'' + S D - S W)$

For minimum values of U

$$\frac{d U}{d W} = 2 (R + s - 1) W + D - S D - B'' - S D = 0$$

Whence $W = \frac{B'' + (2 S - 1) D}{2 (R + S - 1)}$

To apply this formula, we will compute the ratio of cost from that of 24 x 24½ x 50-foot crib, which contains 29,400 cubic feet in volume.

Prices intended to represent probable cost of material in place, with 15 per cent. for contractor's profit and 10 per cent. for risk:

Pine timber, 76,700 feet B. M., at $30	$2,302.00
Iron fastenings, 5257 pounds, at $3.50	180.00
Stone ballast, 162 cords, at $7	1,134.00
Cost of 50 linear feet, or 29,400 cubic feet	$3,616.00
Cost per cubic foot of timber pier	0.123
Cost per cubic foot of stone for embankment, at $6 per cord	0.047

Ratio of former to latter: R = 2.6.

TABLE FROM FORMULA WITH S = ⅔ AND B″ = 16 FEET.

Depth of Water. Feet.	D = Depth of Entire Breakwater. Feet.	W = Economic Width of Timber Pier. Feet.
10	16	7.7
20	26	11.0
30	36	14.2
40	46	17.4
50	56	20.7
60	66	23.9
70	76	27.1

The ratio of cost would vary somewhat with the different widths, but not enough to affect the results materially. For stability of structure, the widths are increased over those given by the calculations. In shallow water the least width used is generally 16 feet, with 24 feet as common practice in water from 20 to 50 feet deep.

CONDITIONS EXISTING AT AGATE BAY.

We will now consider the conditions existing at Agate Bay, Two Harbors, Minn.

Agate Bay is the western one of two contiguous bays which give to the town the name of Two Harbors. As shown in Fig. 11, the harbor is very nearly a semicircle of 2000 feet radius, the direction of the opening being a little east of south. The general trend of the shore in its vicinity is northeast and southwest. The prevailing storms come from the northeast. It is protected from the direct force of these by the point between it and Burlington Bay, but the reverse swells from the northeasters come into the harbor with considerable force. A few hard storms each year come from the southwest. To these the harbor was almost fully exposed.

The line of 18 feet depth of water was only about 600 feet from the shore in the farthest place and the water is 60 feet or

more deep in the center of the entrance, so there was plenty of water for the largest vessels. This bay was decided upon by the Duluth and Iron Range Railroad as their port for shipping iron ore, and in 1883-1884 the first ore dock was built. Now there are five ore docks, with a combined capacity of 162,040 tons, a merchandise dock, used largely in shipping lumber, and a coal dock.

In addition to its shipping interests Agate Bay is frequently used as a harbor of refuge by vessels going to or from the harbor of Duluth and Superior.

HISTORY OF WORK PREVIOUSLY DONE.

The original project was to build 1000 linear feet of breakwater from the east side and 900 feet on the west side, on a direct line toward each other, with an opening of 1340 feet between them, these to enclose an area of 109 acres. The estimated cost was $244,208. This project was approved January 4, 1887.

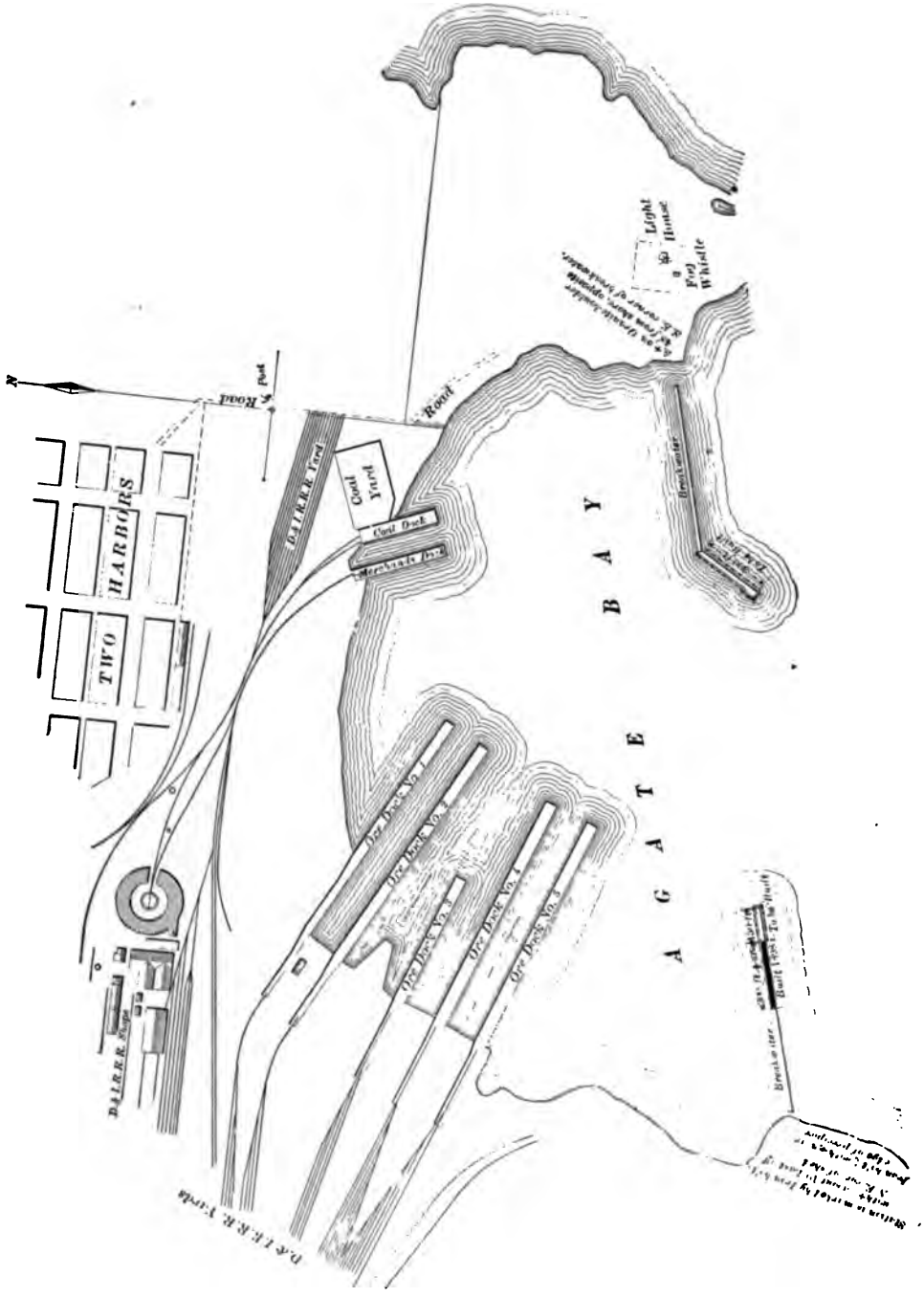
Four hundred linear feet of East breakwater was built in 1887, 16 and 20 feet wide; 150 feet in 1889, 20 and 24 feet wide; 200 feet in 1891, 24 feet wide. This first 750 linear feet cost $61,384.59.

The West breakwater was built as follows: 200 linear feet in 1893; 400 feet of embankment in 1895 and 1896; 250 feet of cribs and superstructure in 1896; 410 feet of embankment in 1897, and 300 feet of cribs and superstructure in 1898. In October, 1896, a large vessel went adrift in a heavy storm, and struck the uncompleted end of the West breakwater, carrying away and destroying 100 linear feet of cribs. One of the 50-foot cribs was not broken to pieces; but was pushed over the side of the embankment into the harbor. It still lies there, with its top corner about 10 feet below the surface of the water. The end of the adjoining crib, which remained on the bank, was moved into the harbor about 8 feet, necessitating a jog of about 6 feet in the alignment and some special fitting, in order to connect solidly.

The appropriations by Congress for the work were made as follows:

August 5, 1889	$22,500
August 11, 1888	15,000
September 19, 1890	25,000
July 13, 1892	30,000
August 18, 1894	30,000
June 3, 1896	50,000
March 3, 1899	71,000
Total	$244,208

BREAKWATER EXTENSION PLANS.



The balance unexpended July 1, 1899, was $72,227.48. Of this amount about $27,000 was covered by contract for the riprap embankment to complete the East breakwater.

In 1897 $1150 was spent in repairing East breakwater. Further repairs are necessary to replace rotten deck plank and side wall of superstructure where broken by collision of a vessel.

REQUIREMENTS FOR FINAL EXTENSIONS.

On March 23, 1899, the Chief of Engineers, United States Army, approved of building 300 linear feet at the end of East breakwater at an angle of 45 degrees toward the lake, instead of the final 250 feet in the straight line of the original project. This gives to the ore docks additional protection from northeasters. While it does not give to the harbor any additional protection from southwestern storms, the flare in that direction is not sufficient to cause additional disturbance. The change also affords additional room for handling the large vessels going to and leaving the ore docks.

Had the increase in the amount of iron ore shipped from this port and in the size of the vessels carrying it been foreseen at the time the breakwaters were first planned, undoubtedly they would have been built farther out into the lake.

At the time of the approval of the change of plans, March 23, 1899, there remained to be built, to complete the project, 150 linear feet of cribs and superstructure on the West breakwater, and 313 linear feet or riprap embankment and 310 linear feet of cribs and superstructure of the East breakwater.

APPLICATION OF THE GENERAL PRINCIPLES AND THEORY OF PROPORTIONS.

Comparing the accompanying plan with the general principles laid down by the Engineer Board of 1853, the form of breakwater is seen to fulfill the conditions therein expressed. The foundation crib is rectangular, of greater width than depth and symmetrical, which throws the center of gravity well down and allows the crib to be towed without danger of overturning. Cribs of similar plan have been towed 125 miles upon Lake Superior. In the latest design the outer wall of superstructure has a slope of 1 to 1, so its weight and the forces exerted upon it are not entirely carried by the wall of the crib. The force is not exerted upon unsupported tie beams, however, for the tie beams are supported continuously, from a point under the top of the slope to the bottom of the crib. The condition that the walls should be of such form that the rubble stone would bear well against the sides was formulated with the idea of having no ballast floor, the

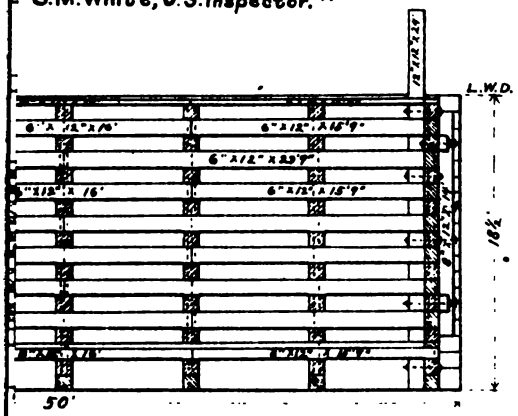
REAKWATERS AT AGATE BAY, MINN.
TIONS FROM

WATER EXTENSIONS

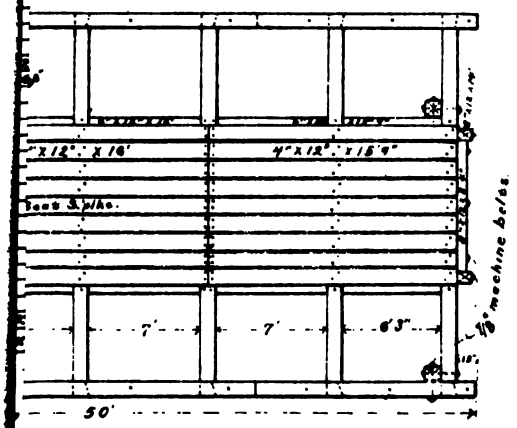
BAY, MINN.

ATIONS DATED DEC. 15, 1899.

he direction of Major
rps of Engineers, U.S.
S.M.White, U.S.Inspector."



CTION OF 18½'x24'x50' CRIB.



VIEW OF CRIB.

pressure of the stone against the sides holding the crib down against its buoyancy as well as receiving external forces. In more recent practice, however, center pockets with floored bottoms are put in and the buoyancy is more quickly overcome.

In the table, worked out under the theory of economic proportions, the prices and other data used were taken so as to apply to this work. The extension of East breakwater lies in from 38 to 60 feet depth of water. From the table, the width for 40 feet is 17.4 feet, for 50 feet it is 20.7 feet, and for 60 feet it is 23.9 feet. These are all seen to be less than 24 feet, which was the width of the preceding portion of the structure. This width of 24 feet was found to be necessary for stability, as, during the cessation of work from 1889 to 1891, the 20 feet by 20 feet pier was moved 2 feet laterally at the end. Hence, 24 feet by 24 feet is the proper section for cribs and superstructure in this place. On the west side the conditions are about the same, so that 24 feet by 24 feet is the proper section here also.

At the end of East breakwater is placed a Government light, and being very close to the course usually taken by vessels in entering the harbor, it was desirable also to have the end more prominent; so it was decided to make the superstructure, over the end crib, 10 feet above low-water datum, or 4 feet higher than the rest, making a total height of crib and superstructure of 28.5 feet. This outer crib being very much exposed to the action of storms, the width was made a little greater than the height, or 30 feet.

LENGTH OF CRIBS.

The proper cross-section having been determined, the length of cribs should be considered next. This should be such that the crib will have sufficient weight to withstand any concentrated shock which it is likely to receive; but at the same time the crib should not be too long to be readily handled. If very long, the crib might not come to a solid bearing throughout its entire length. The full weight of rock would then deform the structure to put very heavy strains on some of its parts.

The chief objection to a long crib, however, is that it takes so much rock to sink and fill it that there is great danger of a storm coming up and wrecking it before it can be made secure. The length which can be safely handled depends in a large measure upon the size of the outfit employed. A contract of the size of that called for by these extensions does not warrant the use of a very large outfit. Two good-sized scows (of not less than 200 tons capacity), and a tug to handle them, are all that could be expected where the rock was obtained not more than 4 or 5 miles

away. A crib longer than 50 feet could hardly be made safe in one day with this outfit under ordinary conditions, and one day is as long as the weather can usually be depended upon to remain good. Hence, 50 feet was the length of crib decided upon.

Contractors with a quite complete outfit for this work sometimes prefer to build cribs of 100 feet length. Under the usual Government specifications the crib is at the contractor's risk until it is completely filled with rock, the ballast boxes planked over and the required riprap placed around the sides. Hence, if the contractor is seen to have a sufficient outfit, he is usually allowed the privilege of building cribs of 100 feet length where practicable.

CALCULATIONS AS TO STRENGTH OF VARIOUS PARTS.

Having determined the proper dimensions of the crib as a whole, let us now consider the proper dimensions of its composite parts. In this case, where we have to continue, with a similar design, a project which has already been partly completed, all we need to do is to check the dimensions of some of the principal parts.

The most important part of the frame structure is the exterior wall. In the preceding construction, and in nearly universal practice, 12 x 12-inch white or Norway pine is used.

In the preceding plan these were supported against the side pressure, at intervals of 7 feet, by the tie beams. Hence, we will consider the strength of a 12 x 12-inch pine beam 7 feet long. Using Trautwine's formula for a beam supported at both ends, $w = \frac{12.5\ bd^2}{l}$ (all in inches), we obtain 37,000 pounds as the safe quiescent load.

The timbers are held against the external pressure in a large measure by the contained rock, so the outward pressure of the rock is the principal stress. The depth of rock in the side pockets is 24 feet. The bottom 4 feet may be disregarded for side pressure, as it is counterbalanced by the side riprap. 5.5 feet by 7 feet by 20 feet = 770 cubic feet, or 6 cords. The average weight of a cord of the rock used here is 6 tons, or 12,000 pounds. Three-fourths of this rock is under water, and thus loses about one-third of its effectual weight. Deducting one-quarter, we have the effectual weight, 54,000 pounds. If this were a liquid, 54,000 pounds would be the side pressure, but for stone it is probably not over half this, or 27,000 pounds. This is well under the 37,000 pounds strength of timber beam.

The dovetailed end of the tie beam is subject to a shearing strain. The section subject to shear is 12 inches by 12 inches

= 144 square inches. Using 300 pounds per square inch as the ultimate strength, the total resistance to shear is found to be 43,200 pounds. This is rather close to the probable greatest pressure of 27,000 pounds; but only the lower timbers have to stand this strain, and I think the tightening of the joints, by swelling under water, increases their resistance to shearing. I have never heard of one of these joints failing.

The drift bolts used in the preceding plan were of ⅞-inch round iron. The area is very nearly 0.6 square inch. At 40,000 pounds per square inch, the ultimate shearing strength of a bolt is 24,000 pounds. The least number used between ties and joining two timbers is two. If the greatest pressure of rock of 27,000 pounds were to act to separate two timbers, this strength of bolt would not be a safe one; but the pressure will act on several timbers combined.

The other sizes of timber and iron are of minor importance, and they have been determined largely by experience.

REASON FOR BALLAST BOXES AND OPEN SIDE POCKETS.

As previously mentioned, the first cribs for construction of this kind were built without any bottom flooring. They then had to be sunk by putting a temporary floor over parts of the top and covering this with sufficient rock to sink the crib. After being sunk to the proper position in this way, the crib was filled inside, and it would have to be filled full before it would be secure against even a small storm. The object in having the bottom open was to have the rock filling bind itself as securely as possible into the earth bottom or rock embankment underneath. The crib then simply acted to hold the rock in the shape of a wall. The placing of the rock on top required considerable care and time, and the space it occupied interfered considerably with the filling of the pockets. To overcome these objections in sinking and make the crib more secure in case of a storm arising before its filling and covering were completed, ballast floors were placed in the bottom of the middle pockets.

The open sides of pockets leave sufficient space for the rock to bind itself into the bottom or embankment beneath. To make a solid structure this is most needed at the sides to take the thrust of the waves as well as make it more stable of itself.

METHOD OF SINKING.

When the crib is built with the intention of having it sunk entirely below (or at least to) the water surface, as required here, it should be sunk while at its mooring in the harbor until only about 2 feet of the walls are out of water. The embankment or

bottom having been leveled to the proper height and the scows fully loaded with suitable rock, with more rock ready for loading, the crib is ready to be sunk. After this, as soon as a calm morning arrives, with indications that the weather will remain good, the crib is taken out and secured in place. Various methods of securing are used, according to locality and circumstances. After other cribs are in, as in this case, the inner end is secured to the preceding crib. Turnbuckles are best for pulling them tightly together. The inner end is held from moving laterally by means of projecting spurs engaging upright guide posts on the end of the preceding crib.

A very efficient means of holding the crib in place, and especially to the proper level, is with guide poles secured in the corners of the crib, so as to be let down upon the bottom and project far enough above the top to allow of efficient use of blocks and tackle. The weight of the crib is then placed upon these before it is sunk clear down and its level largely controlled by their use. It is best to do the last part of the sinking to grade by means of rock placed on top, so that during the first part of the operation it may be raised by moving the rock if necessary. The crib is held a little above the final grade, to allow for settlement in filling and also afterward under the action of storms.

As soon as the crib is at the proper line and grade, small stones, not over 6 inches on a side and preferably cobble stones, are thrown into the open pockets and around the sides of the wall, so that they will work under the walls and bottom timbers and give the crib a firm and even bearing all around.

When these small stones are about 2½ feet above the bottom in all the open pockets, stones ranging in size up to 2 feet on a side are thrown into all the pockets as nearly equally as possible. The stones in the ballast boxes are large enough not to work out between the side timbers. When full, the ballast boxes are covered over with plank well spiked, and large riprap stones are placed around the sides as soon as possible. The crib is then deemed secure against any storm, and is accepted by the Government.

BUILDING OF SUPERSTRUCTURE.

The crib is given at least two weeks in which to settle before the superstructure is started. The superstructure is made level on top. In case of undue settlement extra timber must be placed upon the crib. Generally the leveling is done by varying the thickness of the first timber of the superstructure. No timber under 2 inches thick must be used in leveling. In the superstructure, with 1 to 1 slope on the face, the vertical wall on the harbor

side is leveled first and the bottom course of tie beams is leveled out from this.

The superstructure of West breakwater has a vertical face, while that for the extension of East breakwater has a 1 to 1 slope. West breakwater extension is made vertical because it is an extension, in the same line, of cribs and superstructure of the same design, and is only 150 feet long. The 1 to 1 slope is of recent design for timber crib superstructure, which, it is thought, receives less shock from heavy seas than does the vertical-faced type. The extension of East breakwater is at an angle of 45 degrees into the lake from the preceding portion, which brings it more nearly at right angles to the prevailing heavy storms. Hence, the safest design should be adopted. With heavy waves striking against the 1 to 1 slope, part of the force acts downward, with no tendency to overturn or move the crib; while with the vertical face all the force would act to overturn or move. On account of the change in direction the change in form does not mar the appearance of the structure. Waves roll over the sloping-faced form more easily than over the vertical-faced form; but this does not make the harbor rougher, for the wave form does not go beyond the breakwater.

Further particulars as to the building of cribs and superstructure are explained by the plans and specifications.

BUILDING OF EMBANKMENT.

As the last contract did not include the building of any embankment, I have merely mentioned the building of embankment heretofore.

The embankment was built of trap rock and Duluth granite. The trap rock was obtained from the point between Agate and Burlington Bays, hence very close to the work. Most of the cribs were filled with this also; all in the last contract. The Duluth granite was obtained about 5 miles up the shore, where the quarry was more easy to work; the rock, when blasted out, rolling to the water's edge. At both places it was loaded on to scows by derricks, either on the scows or on the shore. This rock weighs from 175 to 180 pounds per cubic foot, or 6 to 6½ tons to the measured cord.

The core of the embankment was made of any sized rock above 20 pounds weight. The slopes were covered with angular stones weighing not less than 2 tons.

COMPLETION.

The construction of these extensions, in accordance with the plans herein described, was successfully completed November 1, 1901. This finished the projected improvement of the harbor by the Government.

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PHILADELPHIA

YEAR BOOK

OF

THE SOCIETY OF ENGINEERS.

1903

TABLE OF CONTENTS.

MECHANICAL AND ELECTRICAL BUILDINGS.....Frontispiece

COLLEGE OF ENGINEERING..... 5

ENGINEERING OPPORTUNITIES IN THE PHILIPPINES—*J. N. Munro*.. 13

ECONOMY IN FOUNDRY MANAGEMENT—*C. F. Bohn*..... 22

MUNICIPAL CIVIL SERVICE—*G. W. Sublette*..... 29

STEAM BOILER EXPLOSIONS—*Victor Hugo*..... 32

SWITCHBOARD DESIGN—*Arthur L. Abbott*..... 36

TRAINING OF THE SPECIAL APPRENTICE..... 48

COST OF ENGINEERING CONSTRUCTION—*L. E. Ashbaugh* 51

HORSE POWER OF STEAM ENGINES—*E. C. Oliver*..... 55

EVERETT, WASH., POWER PLANT—*E. P. Burch*..... 60

ANNOUNCEMENT.

The YEAR BOOK is a scientific publication issued by the Society of Engineers, of the College of Engineering and the Mechanic Arts, University of Minnesota.

It is essentially technical in its scope, aiming to present articles contributed by honorary and active members of the society which will be of interest and value to the practical engineer as well as the student.

It is, as usual, in charge of an editorial staff elected from the Departments of Civil, Electrical and Mechanical Engineering.

This opportunity is taken to call attention to an error in the volume number, begun in the YEAR BOOK for 1899, which was the seventh issue instead of the sixth. This error, which has continued to the present time, was brought to our notice by Mr. Walter M. Smith, librarian of the University of Wisconsin, and is corrected in this issue, which is the eleventh annual publication of the YEAR BOOK.

The price of the YEAR BOOK is fifty cents. Copies of previous years may be had by addressing

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Mechanical and Electrical Buildings

YEAR BOOK

OF

The Society of Engineers

UNIVERSITY OF MINNESOTA

MAY, 1903 VOL. 11

THE COLLEGE OF ENGINEERING.

The College of Engineering and the Mechanics Arts has kept pace with the other colleges of the University in the remarkable growth of the past fifteen years. But while the other colleges were being provided with new buildings the rapid increase in the size of the engineering classes was for a long time not accompanied by any increase in accommodations or facilities and each freshman class was crowded into the space that was none too ample for its early predecessors. The present senior class remembers the old Mechanics Arts building when the machine shop occupied what is now the drawing room on the basement floor, when the entire foundry including the cupola, brass furnace and core ovens was contained in the small computing and air brake room. As freshmen they took their pattern work when the carpentry and pattern shop was across the hall from the old machine shop in half of what is now the lower mechanical laboratory. The old building then contained the entire mechanical as well as the civil and art departments.

The electrical together with the physics department with all their laboratories occupied half of the present chemistry building while the chemistry department used the remainder of the building. Under such conditions any further increase of numbers without complete demoralization was impossible.

In the Year Book for 1900 was published an outline of the plans for a new building to contain the shops of the mechanical department, the erection of which had been made possible by legislative appropriation. The entire college began to hope for better days and to see relief from the crowding and cramping that was curtailing the work and making it extremely unsatisfactory to student and professor alike. The same summer that the shops were under construction the physics and electrical departments were moved to

temporary quarters in the Armory to allow the remodeling of the chemistry building and to await the construction of more ample quarters of their own.

The conditions that existed only three years ago and the expedients that were resorted to stand in striking contrast with the situation today in the various departments of the College of Engineering. The shops have now been occupied for two years and an addition to that building provides offices and class rooms for the mechanical department while both the electrical and physical departments have moved into new and complete buildings erected to fulfill their special needs and aims. The accompanying illustrations (the first that have been published) show some of the features of the various buildings and the pictures are a better testimony to the advantages of the new well lighted and well arranged class rooms, libraries, shops and laboratories than many pages of description. Many things are still needed to make the various departments as complete as they will be when it is possible to continue the present plans, nevertheless, stopping to consider and compare, it must be admitted the college has fared very well in the immediate past.

That the increased accommodations came none to soon may be well shown by a few comparisons of the classes of the year 1898-99 with those of 1902-03. In the former year the freshman class in woodwork numbered 38 including civils, mechanicals and electri-

CORNER OF A DRAWING ROOM

ELECTRICAL LABORATORY

cals; this past year 116 freshmen took the work and the increased facilities warranted the increase of the time from six to ten hours per week. In 1898-99 the subject of mechanism was taken by 12 men increasing in 1902-03 to 78. The number taking work in the machine shop increased from 20 to 99 while the mechanical laboratory has this last year accommodated 110 juniors and seniors as against 40 four years ago. Great increases in the time devoted to the most important of the engineering subjects have been made all through the courses while some subjects have been dispensed with or put in the list of electives, all of which it is believed is greatly strengthening the work. Several new courses have been added including municipal and sanitary engineering and in connection therewith a course in bacteriology under Prof. Westbrook. This work will be offered next year for the first time. During the past semester Prof. Flather has added to his work a course in the design of small power plants and pumping stations which has been very popular with the seniors.

Many further changes and betterments are in prospect for the near future. It is expected during the coming summer to completely remodel the old Mechanics Arts building with the idea of making it habitable and providing larger recitation and draughting rooms by using the space more advantageously. It is possible that a second story will be built over the present engine room. Probably

MECHANICS SHOP
STAIRWAY
LIBRARY
PHYSICAL LABORATORY
PRECISION ROOM

the mechanical laboratory will be left in its present inadequate quarters but the changes will be made looking to its ultimate removal to a location adjacent to the power plant. This summer will also see the removal of the forge shop to the mechanical building where an entirely new equipment will be provided including twenty-four forges fitted with down draft, two gas furnaces and annealing ovens for the special treatment of steel and for case hardening; also a power hammer and such additional tools as are necessary to make a complete and up-to-date installation. The

CARPENTRY AND PATTERN SHOP

power for blowers and hammer will be provided by electric motors.

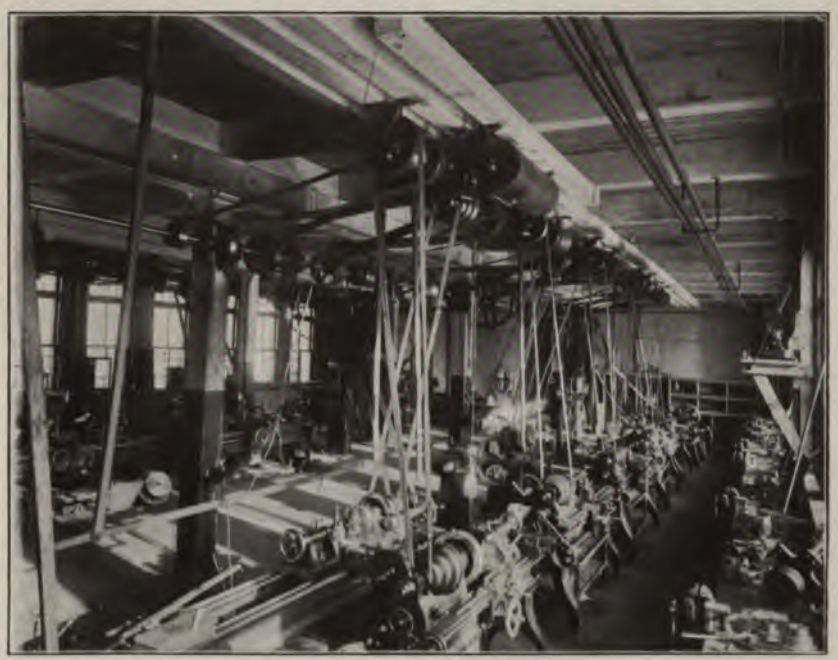
The space now occupied by the forge shop will be used as a cement and concrete laboratory while space will also be found for an hydraulic laboratory and a good roads laboratory under the direction of Prof. Hoag. In addition to these innovations the equipment of the civil department in the way of instruments will be largely increased.

The appropriation of $10,000 made by the recent legislature for the power plant will be used towards the completion of the plant with the intention of supplying light and power to the entire campus. The plant at present consists of a 132 horse-power Cahall (B. and W. type) boiler for 250 pounds working pressure and a Bros horizontal tubular 60"x16' 100 horse-power boiler for a working pressure of 175 pounds. The chimney of Alphonse Custodis

AIR BRAKE AND COMPUTING ROOM

ELECTRICAL LIBRARY

brick is 39 inches in diameter and 100 feet high while a 70" Sturtevant fan is installed in the boiler room to give additional chimney capacity when needed. A Sorge-Cochran purifier system is installed consisting of a 300 horse-power feed water heater with a chemical purifier tank. In addition to the Allfree 10"x13" special automatic engine now in use it is hoped before the next winter's load comes on the plant to complete the installation of a 150 horse-power Corliss engine presented to the college by the Twin City Iron Works and being built by the Minneapolis Steel and Machin-



MACHINE SHOP

ery Company. This engine will be cross-compound and especially built for testing purposes being so constructed that either cylinder may be run separately and the shaft will be arranged to couple the cranks at any desired angle. The equipment of the plant will include a condenser which may be used on either engine.

The plant is run through a jack shaft mounted on roller bearings and equipped with cutoff couplings through one of which power can be provided to the electrical laboratory by means of a rope drive. The electrical equipment of the plant consists at present of two 40 K. W. 110 volt machines from which power is distributed by a three wire system. Two more dynamos are to be installed and the plans involve the future addition of a direct connected unit. The switchboard is a handsome one of light marble in six panels, four for machines and two for distribution.

Although the available appropriation is entirely inadequate to equip the plant to take care of the heavy demand for current which occurs during the winter months the matter is being pushed energetically with the expectation that a more satisfactory condition will obtain in the near future.

The electrical department is making a feature of numerous lectures by prominent engineers and endeavors to put the students in touch with the active commercial life and progress of the day. In furthering this end the past year has seen a complete and successful test of the large storage battery plant of the Twin City Rapid Transit Co. A considerable amount of commercial testing and standardization of instruments is done and for this purpose an admirable equipment of certified standards is available. The rooms provided for photometry and photography are particularly novel and convenient in their arrangement. An innovation of the past year that has been much appreciated by the students is the meetings of the Minnesota branch of the American Institute of Electrical Engineers which are held monthly in the electrical building and to which the students are welcomed.

It is impossible under present limitations of space to go into any details of departmental equipment which is more within the range of the college catalogue but enough has been said to give an idea of the improvements that have been made and are in store for the immediate future. It is a statement over which graduate and undergraduate may well wax enthusiastic.

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ENGINEERING PROGRESS AND OPPORTUNITIES IN THE PHILIPPINES.

J. N. MUNRO, 1st Lt., 14th Cav., U. S. A.

The article which follows was written by request of the management of the Year Book, and not volunteered by the writer. It is not intended to be technical in any respect, and must be taken merely as the observations of an individual, who does not belong to the technical branch of his profession. His conclusions may be correct or not, but such as they are they will be presented as briefly as possible.

The writer's experience extended over a period from July, 1899, to September, 1901, and was confined wholly to the island of Luzon, which is, in general progress, perhaps, the most advanced of the archipelago.

Like all undeveloped countries, the Philippine Islands present opportunities to the business and professional man that are almost unlimited. The opportunity for the engineer is at least equal to that of the other professions, and, in the opinion of the writer, they are far greater. Every branch of the profession is undeveloped. But *now* is the accepted time. The professional man who wishes to rapidly become independent, to take advantake of the openings in Uncle Sam's new possessions and establish himself, must cast behind him all thoughts of the inconveniences to be endured, the separation from home and friends, and the exasperating conditions under which he must work, and go forth and "get busy." Let us consider first the civil engineer and his profession. Perhaps the nature of my work led me to think more often of him and see more of his opportunities than of the other members of the profession.

To begin with, the country is almost entirely unmapped, or rather, it is entirely, but very badly mapped. One of the first maps with which the writer had anything to do in the Philippines, showed the very important town of San Fernando (Pampanga), ten miles from the railroad. As a matter of fact this town is an important railroad station only forty-five miles from Manila. This is simply a sample. Not a single map was correct. The Filipino himself was not much of a map-maker, or at least he didn't work at it, and the Spaniard had to make his maps under conditions which were, to say the least, not encouraging. The Spaniard had, however, an active imagination, and was never at a loss to fill in those portions of the topography

which he deemed it unwise to investigate too closely. Since the American occupation, some work has been done in the topographical line by the military, and is perhaps being pursued at present by the civil government, but it can be little more than a beginning and a vast country is still waiting to be mapped, and must be mapped. Some one will be paid to do it; who will it be?

Let us turn our attention now to the highways, byways, and waterways of the Philippines. Just as the question of transportation may be the making or ruin of a great army, so may it be the making or ruin of a nation. No matter what the resources of a country may be, until it has the ready means to transport its products, it will never figure in international competition. If we wish an example of what transportation can do for a country, consider our own. Now the Philippines have resources untold and we must get at them.

There is at present but one railroad in the islands running north from Manila to Dagupan, roughly parallel to the west coast of Luzon, with a total mileage of about 115 miles. It was built and operated by an English company. It is neither standard nor narrow gauge. In August, 1901, it was running perhaps six trains daily, and the round trip took twenty-four hours. This road by no means passes through the most important towns or through the richest territory of the island. East of the railroad are the rich valleys of the Rio Grande de Pampanga and the Rio Chico, dependent entirely on wheel transportation or water transportation, which latter is, at best, uncertain.

Leaving the railroad at San Fernando and following the main wagon road first east and then north, one passes through the following towns in a distance of thirty-nine miles: Mexico, a sugar center; Santa Ana, a sugar center; Arayat, at the foot of Mt. Arayat (a lone mountain standing on the plain with a basal circumference of twenty-one miles, and covered from top to bottom with fine timber), a sugar, timber and rice center, situated on the Rio Grande de Pampanga; Cabiao, a rice center on the same river; San Isidro, a large town, capital of the province of Nueva Ecipa, at the junction of the Rio Grande and Chico, a timber and rice center. Now taking the road east along the Chico, we come to Gapan, a rice center, and finally to Penaranda and the last town on the Chico almost at the foot of a mountain range rich in timber and possibly mineral. All this in thirty-nine miles, every one a large town with almost numberless outlying barrios (small villages subject to the municipal government of the town to which they pertain). When the country adjacent to the foregoing towns attains its proper development, its products must be accommodated. The two means now available are the roads and the river. If roads are to be depended on they must

be built. The alleged roads that existed two years ago are, except in the dry season, unworthy of the name. The only improvement made on the main road mentioned above was from San Isidro to Arayat, a distance of nineteen miles. This was done by the military with what appropriation they could secure, and consisted of a species of macadamizing with gravel and putting in large lateral ditches to accommodate the enormous amount of rainfall of the wet season. One-half of this road was under the supervision of an engineer officer and the other half under that of a young volunteer line officer who had been a civil engineer. Whether it withstood the attacks of the rainy season, the writer is unable to state.

It is useless for me to go into details of what is required in the various sections of a country which is doubtless as unfamiliar to the average reader as ancient Troy, though entirely too familiar to the writer. The section of country chosen is merely an example taken as characteristic of the better developed portions of the island, a vast country whose resources are not yet even guessed.

To return to our example, then, let us consider it from a water transportation standpoint. The Chico is considered unnavigable and therefore eliminated. Whether the Rio Grande is ever to be more than temporarily navigable is a question for the engineer. During the greater part of the year it was used by the military for gunboats and light draught launches, from Calumpit on the railroad to Cabiao, six miles below San Isidro. From Calumpit south and west to the bay it was navigated practically the year round. Occasionally in high water boats could run from Cabiao to San Isidro, and during Gen. Lawton's northern campaign a boat succeeded in getting to Santa Rosa, eleven miles (by road) above San Isidro. These boats drew from three to five feet of water, and were not at all suited to the character of the stream. The stream itself is a vexing problem for any one. The volume of water varies enormously during the different seasons of the year. The bottom is constantly changing and bars forming, making the channel a variable quantity. Snags, due to the cutting of the banks, are a great source of annoyance. It has been suggested that boats constructed on the plan of those that formerly navigated the upper Missouri, and which were said to be able to run across country on a heavy dew, would be adapted to the Rio Grande. Although the writer never saw the boats referred to, he has been informed, on good authority, that they were stern-wheelers, of extremely light draught, and that in going down stream when they struck a sand bar which had formed since their up trip, they simply backed up to it, worked it off with the wheel until they could slide over, swung round, and pro-

ceeded on their way. Leaving the boat question aside, the questions before the engineer are two: to make the channel more or less constant, and to prevent the banks from undercutting, thereby keeping the river in its course. The varying volume of water makes these two problems worthy of the steel of any ambitious engineer. The transportation of produce must, for a time at least, be by wagon road. Here is work a plenty for years to come. The writer saw but few made roads in the Philippines. Those that showed evidences of having been carefully constructed, were nearly all paved, in a fashion, with cobble stones, some with flat rocks, and had at one time been a species of military road, but had long since became worse than no road at all from lack of care, the cobble stones sticking up at all angles and washed into heaps by the enormous rainfall of the wet season. Except on the railroad but few bridges had been constructed on the approved plan of the bridge builder.

Examples might be given indefinitely of the opportunities open to the civil engineer and the lack of progress made thus far in the line of his profession. The example given is, however, sufficient to illustrate, and if you will take a reasonably large map of the Philippines and the piece of country used in this article as an example, you will find it a very small portion of the island of Luzon, to say nothing of the entire archipelago. The United States government is going to let contract after contract for the making and improvement of roads, rivers and harbors, for surveys and other work of interest to the civil engineer. Already the contract has been let for the improvement of Manila harbor, building the sea wall along the Lunetta, completion of an enormous breakwater and the building of a naval coaling station at Cavite. This is the largest single contract ever let, and involves millions.

To the mechanical engineer the chances are as varied and far-reaching as to the civil engineer. Little or no progress has been made in this direction. All forms of mechanical devices are crude. Take the sugar industry. Many of the processes in the cultivation, harvesting, and manufacture of sugar are of the very crudest. Economy in handling the product is not considered, the waste is therefore large. There is not, or was not, when the writer left the islands (August, 1901), a single sugar refinery. Some few steam engines were used in connection with the very best plants, but nearly all the work was done by hand or horse power machinery, carabao being used in most cases instead of horses.

The same is true of the rice industry. Every operation, from the planting of the seed to the threshing and finally the hulling of the grain, is performed by hand or animal power. There is no

planting, harvesting, threshing, or hulling machinery that ever came under the writer's observation. This in itself is a large field. Consider the lumber industry. The islands are full of the finest hard wood timber that is known to the wood worker, yet nearly all the sawing and operating are down by hand. There are many lumber yards in Manila, in which the sawing plant consists of numerous pairs of Chinamen at opposite ends of so many whipsaws. There are no planers, edgers, stickers, or other machines incident to the manufacture of lumber in the United States. Dimension stuff was almost unobtainable. Some few English sawing plants have been installed, but with all due respect to our English cousins, they were not serious competitors of the Chinaman and his whipsaw. American sawing machinery, however, is rapidly being introduced. The first one to operate successfully in Manila was a little 20 horse power pony mill carrying a single 50-inch inserted tooth saw, with a capacity in soft wood of 10,000 feet per day. Five months after that saw was in operation, a wealthy Chinese building contractor offered $375 per month rent for it, and in addition offered the American mechanic who was operating it $200 per month for his services. Think of the value of that little $1,800 outfit in the city of Manila, when the shrewd Chinaman could see a profit in it at a monthly rental of one-third of its value.

The writer is of the opinion that the circular saw was introduced in the Philippines by Americans, and it is certain that the band saw was. The familiar signs "Lumber, Lath and Shingles," and "Sash, Doors and Blinds," or what they signify, is unknown in Manila, simply because the necessary wood working machinery is undreamed of.

Plants for the repair or manufacture of engines and boilers are unknown, except perhaps for small repairs to marine machinery. The above are simply examples.

Although little progress has been made by the native in mechanical engineering, he is capable of rapid advancement. In the car shops of the railroad company all the workmen are natives or Chinese. The latter did the wood work and the former the iron, brass and steel work. Their compensation was, perhaps, 50 cents or less per day. These same workmen built locomotives complete under the direction of their English employers, and put in repair others which their patriotic brothers had reduced to scrap iron in their endeavor to stop the American advance. Of course these were not complicated or elaborate machines, but they compared favorably in size with our traction threshing engines, and their speed was but little greater until the American soldier climbed into the cab and took the throttle, in which case they

developed a speed which usually sent them into the ditch or the round house inside of a few days.

So much, then, for the mechanical engineer and his field in the Philippines. Page on page might be written giving instances of other crude processes applied at present in the various industries that will some day become mines of wealth to the operators. The hemp and copra (cocoanut) industries are two good examples.

For the mining engineer there are chances that are perhaps not yet apparent to those who have investigated the subject to some extent. If he is unable to find a paying proposition he can at least "salt" one. The writer assumes, of course, that the process of "salting" is a part of the proper education of the mining engineer. Seriously, however, one may say that, two years ago, nothing had been done in the mining line. In the first place, the country was not considered safe, though the writer would consider it much safer than the average American mining camp. In the next place, there were but few men who really came for the purpose of properly investigating the mineral resources of the country. It is, therefore, an open question as to whether really important mineral discoveries in the Philippines will be made or not. It is hardly probable that so great an extent of country with such a varied topography can be wholly without mineral wealth. Now, then, as to what is *known* to exist: Coal has been discovered in at least one place, a small island off the southeast coast of Luzon. In the mountainous province of Bengnet, Northern Luzon, gold is constantly mined in crude fashion and small quantities by the savage tribes of the mountains, especially in the vicinity of Trinidad. Whether this is quartz or placer mining, the writer is unable to state. At the town of Penaranda, where the writer was stationed for several months, also at Gapan, six miles down the Chico, some natives make their living by panning gold. Their pans are rude affairs, but the operators are very skillful in their use. A native considers himself very fortunate if he pans out 50 cents worth of gold in a day. The work is conducted in the fields in the valley of the Chico, along some stream or arroyo, the workmen simply digging a hole in the ground and panning the earth from it until the hole becomes too deep for convenience, when it is abandoned and another begun. An officer, in the native organization to which the writer belonged, had a small nugget which he claimed he discovered digging in one of these abandoned holes until he reached a clay bottom. The nugget referred to was roughly shaped like a small pebble and perhaps a quarter of an inch in its longest diameter. In discussing the existence of gold in this river valley with the presidents of Penaranda, the writer suggested that it would seem to indicate the ex-

istence of a ledge in the mountains to the eastward. The presidente stated that such a ledge did exist and that he had formerly been in the employ of an English miner who had worked the ledge in a small way. He further offered to conduct the writer to the place, who, however was too busy at the time locating the rifles of the Presidente citizens to take advantage of this generous offer.

Personally, the writer is almost totally ignorant of mineral indications so that his own observations are of little value. Many indications of copper were to be found in various places but what their value might be the unsophisticated could not even guess. Rude iron implements are found in the hands of the savage tribes and this, the writer was told, is especially true in Mindanao. That great island is almost a sealed book and much has been predicted for it.

The Philippines may never prove to be an Eldorado, but they are worth investigating.

The progress in electrical engineering in the islands may be said to be about equal to the progress in other engineering branches or, if anything, less; consequently the opportunities for the electrical engineer are perhaps greater. So far as the writer is informed, Manila possesses the only electric light plant in the islands. In the summer of 1899 this plant was in charge of a former student of our University, who had rushed to the rescue of this country with the 13th Minnesota in 1898. Just what the extent of this plant is the writer is unable to say. No electric railroad exists in the islands, although the franchise for thirty miles of trolley line in the city of Manila has recently been granted. This road will, without a doubt, eventually extend through the line of towns along the bay, beginning with Pasay, where the race track and cavalry post now are, there on to Paranaque, Bacoor, San Roque and Cavite. A branch should run south to the towns along Laguna de Bay either by way of San Pedro Macati or Las Pinas, or perhaps by both routes. In almost any direction from Manila are towns of sufficient importance to warrant the extensions of the trolley system. The Filipino is a great traveler and the trains which run into Manila are daily crowded with passengers. The small steam tramway from Manila to Malabon, a distance of less than five miles, is said to be a heavy dividend payer, although it parallels the railroad and is distant from it less than half a mile throughout the greater part of its length.

In a country where important towns of large population are so close together as they are in the Philippines, it seems almost certain that the rural trolley system is best adapted to accommodate the traveling population, to say nothing of the freight. Of course for a time, it might be necessary to warrant a small ma-

chine gun in the motorman's box and possibly one on the rear platform, but these could eventually be removed and the expense of their maintenance would be small.

As the transportation side of electrical engineering was the one that appealed most to the writer, he will not attempt to go into other phases of the question. Whether it was the irony of fate or not, it fell to the fortune of the writer who was a former student in Electrical Engineering in the University of Minnesota, to capture the only native electrical engineer which he has yet heard of. This gentleman was holding the position of Brigadier-General of Engineers in the insurgent army. Perhaps it was because he was in the technical corps that he was so easy. Sometime after he had surrendered and was "accompanying" the writer to Gen. Lawton's headquarters, he opened a conversation on the subject of his profession. Wishing to make himself appear agreeable the writer led him on. Finally he began to question his captor on points in his profession and talk about "watts" and "ohms" and "dx" whereupon the writer was obliged to assume much dignity and told him to cut it out and hit the trail. On later investigation it was found that the distinguished captive had spent almost twenty years in Europe, the greater part of it in France, and had studied electrical engineering a number of years. He was supplied with several dynamos which he had brought across the mountain with much difficulty and over which he almost shed tears when informed that they must be abandoned. His headquarters were thoroughly equipped with electric bells and push buttons. He had used a small engine in running his dynamos, but this he had been obliged to abandon on account of the rapid American advance. He eagerly inquired if the writer had seen his engine in passing through San José and expressed a hope that it might yet be recovered, but was much grieved and shocked when informed that it had not only been seen but had been reduced as far as practicable to scrap iron. The above is related simply to show that, though little progress has been made in engineering in the Philippines, much may be made and that very shortly. Filipino young men are entering our schools and colleges by scores and there are few people who are more eager for education than the natives of our distant island possessions.

To the architectural engineer the field of action in the Philippines is at present almost limitless. He must accommodate his ideas to the new climate but if there is one thing needed above another in Manila and the other important towns it is sanitary architecture, and buildings contructed with a view to comfort, economy of space, and convenience. Nothing is really known of architecture in the islands. Just now the civil government will be contracting for office buildings, government buildings, school

houses and perhaps college buildings. The War Department must let large contracts for barracks and quarters, store houses, stables, etc. Office buildings for rent are much in demand and in the residence class of buildings the field is limitless. The man who can go to Manila and put in a class of buildings on the principle of our American summer cottage with the necessary changes for a tropical climate can inside of a few years sit in a game with Rockefeller. To go into details of this branch of engineering would be simply taking up space without adding to what has already been said.

In this article the writer has endeavored to show something of engineering progress in the Philippines and the chances for the young, energetic engineer in that field. It must be taken for what it is worth and not considered as advice to any reader to go there.

ECONOMY IN FOUNDRY EQUIPMENT AND MANAGEMENT.

CARL F. BOHN, '04.

"Advancement toward perfection," as a byword of the Ameriman manufacturer and engineer, through its keen application in the desire for the betterment of manufactured products, has pushed American methods far to the front. Economical production has reached a stage wonderful in its completeness in the producing of the higher grades of labor saving and product improving machinery.

Foundry advancement has not had such progress. It is but recently that the mind of that factor of American proficiency, the cost reducing engineer, has turned to improved production in the foundry. Ultimately the aim of every foundry is to turn out the higher grades of castings in the most economical manner. The lower the cost of the output with the maintenance of as high or higher standard of production the greater the success of the business. To be real, economy must be rational and based on the practical experience and science of the management.

Owners of foundries should realize that as an establishment increases in size it becomes more and more an assemblage of independent powers which, while working in common harness, have not been homogenous since the day the owners subdivided their control. Usually divided responsibility meets with but one outcome; the loss of unity among workmen and the falling off in profits.

In the present day of active competition, power of other kinds than the mere ability to turn out good castings is required to successfully conduct a foundry. In his choice of a system of working, a manager should bind himself as closely as possible to one of extreme simplicity and should personally carry it forward at all points with the closest attention to detail, remembering that to work systematically is to work successfully. All work in the foundry can ordinarily be traced back to the drafting room or superintendent's office at least this should be the case for no drawing or order should be put into the shop without first passing through the hands of the superintendent or head draftsman. Many condemned castings are caused not through any fault of the moulder, but by sharp angles, no fillets and a general disregard of the laws of crystallization of cast iron directly traceable to the drafting room. It therefore behooves the owner bent

on economizing product, to begin with the draftsmen who should not be selected for their ability to turn out showy drawings but rather for their actual experience in the real work of the foundry, combined with a good technical education. Many firms have lost reliable and valuable men through the poor location of the drafting room which was a detriment to the health and grade of work of the draftsman. The drafting room should be far enough from the works to maintain freedom from the dust and grit ot the foundry. Tracings, standard drawings, shop duplicates, etc., should be systematically filed away in such a manner that any drawing of any date can be found instantly. The card catalogue is invaluable for this purpose. It is reliable, compact and convenient. As a consulting record of stock patterns and standards its use is far in advance of any other method.

Passing to the foundry proper, attention is at once directed to the buildings. Owners when either constructing or remodeling their buildings should realize that the building is not only a covering from the weather but is in reality a tool. Upon its economical design and through its fitness for its purpose depends much of the labor saving and product improving value of the foundry. The construction or remodeling of a building is the most economical when with a minimum cost of material the result is the most lasting. Steel and iron should be selected wherever possible primarily for their first low cost, ease of erection and because of the strength and stability of the buildings. Brick veneer or a combination of concrete and expanded metal has been found to be the best material for side walls and partitions. Slate roofing while high in first cost is best, in that it is practically everlasting and highly fireproof. In all cases adequate provision is made for additions to be added should business increase.

As a rule, lighting and ventilation are the least considered points in the construction of foundry buildings. From an economical standpoint too much attention cannot be given to them. Windows should be in lantern and side walls wherever space is available and wire glass in the roof should guarantee the proper ratio of light to floor space. Moreover the windows should be kept clean from the flying dust incident to foundries. A thin coating of this dust retards light to an extent keenly appreciated by the molder although seldom by the manager. Heating is usually entirely neglected. If the weather be really cold the molder is allowed to light a few kettles and distribute them about the shop, filling it with fumes which are believed to have no effect on the molder. In fact many owners imagine a cold shop to be a promoter of better and faster work through that brisk sprightliness supposed to be incident to a man's endeavor to keep warm. In reality a cold, poorly ventilated shop is killing

in its benumbing influence on a man's ambition and dexterity. A warm blast system over coils of pipe of exhaust steam is sufficient, while yet economical, to heat a shop to a comfortable temperature. In summer the heat being turned off, the blower is operated to drive out the smoke and dust during "pouring off" and "shaking out."

In planning a new, or reorganizing an old foundry too much attention cannot be paid to the arranging of details so that undue handling of pig iron, scrap, coke, flasks, etc., is avoided. An ideal condition is that nothing goes over the same ground twice; raw material coming in at one point and the finished product going out at another.

While the interior is frequently supplied with the best devices for the handling of material it is seldom that the yard is properly fitted. Considering the large amount of material handled it seems that more attention should be paid to it than it ordinarily receives. To quote one writer on the subject, the stock for the cupola is too often raised to the charging floor "by leg power and profanity rather than by mechanical power and profit." The mechanisms for lifting material for charging are too numerous for mention here. A large foundry equipment company has, however, devised a yard system which will at once appeal to the economical manager. By means of a conveyor track and traveling crane covering entire stock yard pig iron, coke and all supplies are unloaded direct from cars and conveyed to any place in the yard or hoisted to the charging platform. Besides serving as charging elevator the traveler is extremely useful in loading cars direct. It carries coal to the boiler room, coke to bins, burnt sand and slag to waste heaps and serves as casting breaker. The range and usefulness of this scheme of service is obvious and will at once appeal to a manager and by him it may be developed to suit individual needs in a way such as to equal in saving of time and labor any other device of the business.

Economically there are openings for great improvements in the handling of material within the foundry. This leads to compressed air and electricity. Compressed air takes predominance by the simplicity of its mechanisms, regularity of action and wonderful range in the facilitating of work. To obtain the true benefits from the installation of a compressed air plant much thought must be placed in the selection of a compressor. By all means a choice of one of at least fifty per cent greater capacity than the present need calls for, is desirable. A cheap compressor in the end invariably proves the most expensive. In general, selection should not be made until efficiency is determined by the actual amount of air delivered with a given fuel consumption. The combining of the practical experience of the pneumatic tool-

maker with close, sound calculation on the part of the manager will bring the highest results with the greatest economy.

When once compressed air is available the number of convenient and economical possibilities it presents are endless. Its use in the pneumatic hoist is perhaps the most important and too well known for more than mention here. Wherever a steady and absolutely safe lift is required it is impossible to replace. With the pneumatic chisel one man can do more work and in a better manner than five men working in the old way. The pneumatic rammer relieves the molder of the monotony and hard labor of ramming up his molds and at the same time performs the work with absolute uniformity thus reducing losses caused by strained castings. The latest appliance is the sand blast which on adoption will demonstrate daily that one man, using a blast consuming approximately 150 feet of air per minute, can clean more surface and remove more cores than is possible for any ten men to remove in the old way. Moreover the surface left by the blast is infinitely better than that left by hand labor. Intricate cores are removed with ease. By freeing the surface of scale, castings are machined with a saving of tools, time and labor. Other pneumatic appliances for the foundry are the sand sifter and mixer, pneumatic drill, rotary sand blast tumblers, and portable hot air drying furnaces for skin drying molds.

Prompt and economical handling of material by crane and trackage systems is of first importance. Traveling cranes through the use of compressed air and electricity are indispensable. While the traveling crane is usually purchased for the carrying of heavy loads, still a large part of its work will be for transporting the medium weight flask, lifting copes and turning molds. It is often necessary to hold such a load for some time while others are waiting for the crane for transportation service. Considering that a traveler is only employed at its maximum efficiency when used on lifts proportional to its capacity, a foundry at Schenectady, N. Y., has evolved a system highly economical in its convenience and adaptability. All columns supporting roof and traveling crane girders are fitted with universal pintles carrying jib cranes of about five tons capacity and twenty to thirty foot swings. The ingenious feature about the cranes is that they may be lifted from column to column by means of the traveling cranes. In this way molders work continuously through the busiest part of the day by the use of nine jib cranes while the traveler can work without interruption in carrying the heavier loads and in the placing of molten metal.

Transportation by trackage is imperative in supplementing crane systems. Tracks should connect main buildings with sand heaps, flask rooms, storage rooms and tettling department.

The adoption of no one improvement in the foundry has caused as much discussion as that of machine molding. Any machine or device which will take from the skilled molder the distasteful monotony of repetition work and allow him to devote his time to the more difficult pieces should be welcomed by the foundry management. The molding machine, such as is fast coming into common use in up-to-date foundries, will benefit both employer and employed. The results desired by the manager are cheaper and better castings. The usual view of the workman is a pleasanter day's work with a larger day's pay. The molding machine has all but granted the wish of both parties. The experienced molder has more pleasure and turns out a better and more paying day's work when he can apply his skill and experience in the more difficult molds. The true manager is gratified when he can turn out work by the cheapest man or machine competent to perform it. Cheapest not meaning in this sense the lowest priced, but cheapest in the light of wages paid, time consumed and quality of work performed. It is always to be borne in mind, however, that the introduction of the molding machine into the foundry should not be made unless the class of work done perfectly fits its capacity. Among the machines on the market at the present day there is such a wide field for choice according to the needs of a foundry and ideas of a buyer that space will not permit the going into the relative designs of molding machines but it is a subject sure of attracting much attention and certain adoption in foundry practice. Founders having long runs of duplicate light castings are able to develop the value of the machine to the greatest extent for it goes directly to the root of the matter of economy in reducing the ratio of the pay roll to the cost of work produced.

Iron as a real factor of the foundry business in its changing condition is a source of continuous perplexity and risk. Great advancement in the requirements for castings have to be met in modern high speed engines, in very high pressure boiler fittings and in many other uses. Foundry supply buyers are therefore correspondingly careful to buy iron which will produce the best results.

In judging of iron, in general, there are two methods in use, the one based on physical and the other on chemical tests. Usually physical tests are based on strength, contraction, deflection and fluidity. In judging by tracture men have grown wonderfully proficient in reading the character of iron. Chemical tests, while depending largely on the elements, carbon, phosphorous, manganese titanium, etc., are by the progressive and practical chemist based on the rule that the elements silicon and sulphur determine the grading of iron.

The keynote of the whole question of iron founding is the decision of whether it is more economical to use high priced irons and mix according to physical tests and fracture or to use low priced and mix by analysis. The first method will without doubt produce nearly perfect castings but the second will accomplish the same or better results with a saving in expense of material and with a certain uniformity of product. Applying chemistry to founding, however does not necessarily mean that a chemist be employed. In foundries of average size quite the contrary view is taken. If a chemist is not employed the question is at once asked, "How can chemical methods be used?" The answer is this, in modern furnace practice it is possible to buy iron on guaranteed chemical constituents. However, the fact remains that despite identical chemical analysis some irons are of more strength than others and that for this reason physical tests should not be discarded.

Having determined the chemical and physical properties of the iron it is stacked in graded piles with identification symbol conspicuously displayed. By thus keeping brands distinct those suspected of an inferior quality are detected by cutting them from the mixtures and noting results. By taking advantage of "off grades," iron may be purchased very cheap and by blending still produce the highest results. To make a success of mixture making a knowledge of not only the pig iron but also of the scrap is necessary. Ordinarily this can be narrowed down to the mere knowing of the silicon and sulphur constituents. Of course scrap is of a variable nature but fortunately castings of known uses are of nearly uniform composition which once determined can be relied upon. Ordinary machine scrap contains never far from 2.00 per cent silicon and is normal in sulphur and phosphorous. Heavy machine castings are also normal in sulphur and phosphorous but contain from 1.50 per cent to 1.75 per cent silicon. Stove plate and similar scrap can be relied upon to contain from 2.60 per cent to 2.85 per cent silicon and one per cent phosphorous. All extraordinary scraps such as car wheels and plate should be barred from mixture unless absolutely sure of the allowance to be made for such material. Now with a highly practical knowledge of material on hand and with a desire for producing an iron of known specifications all that is necessary is the combining of the stock pig iron and scrap according to their known values and with a due regard to maintaining uniformity in furnace changes. This method of the practical application of chemistry is being widely adopted, yet to bring success with it close thinking and highly systematic work is required, but the simplicity of science thus applied will bring the highest results.

In conclusion it may be said that with the achievement of the past few years as a criterion, foundry practice will advance to the position it deserves in the commercial and engineering world of the near future. Close competition will compel the founder to drop his old unreliable methods and rise to the use of scientific knowledge thus advancing to sure and lasting success.

MUNICIPAL CIVIL SERVICE.

G. W. SUBLETTE.
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Civil service according to Enton is for the purpose of the removal of abuses in the public service, and the enforcement therein of such just and sound principles and methods as will most contribute to the best administration of public affairs. As a reform, he says, it has a double aspect—destruction and construction; destruction relating to existing evils and the prevention of their repetition—construction; the educatonal development of public opinion and the adoption of such methods for doing the work of public administrations as will be effective for purity, efficiency and economy.

The principles as set forth above are well understood and their accuracy and practical value are readily perceived. Washington saw the necessity of obtaining men best fitted for all appointive officers as did other presidents down to Jackson. Jackson believed that to the victor belongs the spoils and further believed, just as some people in this day, that man had a right to such appointment and that all men had an equal right to office. The effect of this idea as promulgated and carried out by him has been more or less followed by the governing powers of the nation and has been injected into the state, the city, village and hamlet.

Fifty years ago England saw the evil of this and started a reform beginning with what was called pass examinations, that is when a place was to be filled the appointing officer asked that a certain man be examined for the position. This developed the idea of competitive examinations and a proper civil service. The effect of which was to do more for the advancement of the school system of the kingdom than all else together and places that had been open only to royalty and its friends were divided with the common people.

The idea of civil service has been carried into the municipalities until all appointed officers feel safe and if councils are satisfactory, on regular election days the polls are not opened.

Candidates for high offices were the strongest opponents of civil service but time has proved that it was a blessing to them as they are elected without promises for individual preferment that so often ruin the chances for re-election, as every promise fulfilled makes ten enemies to one friend. In 1867 Thomas A. Jincks, member of congress, begun the agitation of a civil service for appointive officers. Now while much has been done since

then to improve the service in efficiency and economy, still it has many weaknesses and is not sufficiently comprehensive. It is true that Garfield recognized its value and "except for a factional quarrel produced by the strife for patronage as spoils he would not have been murdered." President Harrison before him was worried into his grave by the spoilsman.

Now political parties are a recognized necessity and exist and must always continue to exist so long as man has intelligence and spirit to proclaim his rights. "They are both useful and inevitable under liberal institutions and everything of reforming the civil service is faulty and likely to fail to the extent that it interferes with their true sphere and activity. But parties are not ends in themselves and can claim no rights or interests paramount to those of the people at large. To arouse interest, to express public opinion and sustain political principles and policies until they are made effective in laws is the only object and end of a party."

Now while in the federal, the state, and the municipal governments certain offices must be political there are many more that should be classed under civil service, and since the municipality is a corporation banded together for the mutual good of its citizens for the purpose of promoting health, improving streets, water, sewerage systems, schools, libraries, and public service, the necessity is readily seen for great efficiency in the army of employes that must look after these many interests, there is no place for the patron of the curb boss and petty spoilsman. The man for a place in any one of these must be measured by the amount of character and capacity he may possess for the discharge of official functions. And according to the principles of civil service there can be no just charge for discrimination on any other basis. "He therefore is best qualified who can and will serve the people most faithfully, and should have the highest claims for preferment."

Many cities recognize the importance of civil service and are doing much to increase its efficiency by legislative enactments. The city of Chicago adopted the state civil service act in 1895, the same year that it was passed by the legislature. This act contains all the elements necessary for obtaining the best service for all positions from the laborer on the street to the highest position on the list of civil service appointments. This is more than can be said of the United States civil service, for laborers are not included and the various heads of departments abuse the service by hiring under the guise of laborers, classical help. In the fifth annual report of the commissioners of Chicago attention is called to this in comparing the civil service system of Chicago with that of the United States.

The commission says that should a head of a department in Chicago hire laborers without examination to fill vacancies, the

payroll of that department would be stopped and the guilty party lose his official head, and further that if the commission should allow it in a single instance the aid of the Grand Jury would be invoked and the penitentiary be brought unpleasantly near. For no matter what the public may believe the civil service employes of the city are so well posted upon their rights that they allow no encroachments. This is more than the national government has been able to accomplish. In closing it says that every requisite of a perfect civil service has been embodied in the rules and further says that the principal benefit of civil service is to prevent political appointment or discharges, to grant protection to employes against political persecution or pull, to insure permanent tenure during good behavior and to ensure promotion on merit after examinations.

When civil service is thoroughly established in municipalities and all positions are secured through a well maintained civil service commission, demoralization will cease in the various departments; they will assume a higher and better standing for integrity and efficiency. There can not be an incentive to either integrity or efficiency when every man to keep his place must be a petty politician or ward heeler.

STEAM BOILER EXPLOSIONS.

VICTOR HUGO, M. E., '96.

The manifestation of any force of magnitude creates feelings of wonder and awe, and when the force is uncertain in its action, and its effect cannot be anticipated, there is added fear; and in no one force of which we are aware, does the power to produce these various attributes exist to the same extent as in a steam boiler explosion. When we consider the explosion that occurred at the Penberthy Injector Company's works, in which a large building was wrecked and thirty people killed, or the explosion at the plant of the Detroit Evening Journal, which resulted in even greater property damage and a loss of thirty-seven lives, we realize the magnitude of the force with which we are called upon to deal. Not only is the study of the design and construction of steam generators of interest, but a thorough investigation of the facts and the application of the proper deductions to the prevention of steam boiler explosions is humane, for by consulting the following table which gives the boiler explosions that have occurred in the United States for the past five years, it is seen that every day brings its explosion, with its list of killed and maimed.

	No. Explos'ns	KILLED	INJURED	TOTAL
1901	423	312	646	958
1900	373	268	520	788
1899	383	298	456	754
1898	383	324	577	901
1897	369	398	528	926
Average	387	320	545	865

It is not strange that the extreme violence of these explosions calls forth various explanations, in which the cause is generally ascribed to the development of abnormal forces. Among those who should know better, it is deplorable that truth should be covered with so much nescience, for it prevents the discovery of the true cause and the application of the essential verity to the prevention of a recurrence of the effect in future. Among those who are not ignorant of the latent energy in a steam boiler, and who, after an explosion, use an explanation of the existence of some monstrous force to hide their own carelessness or neglect—it is criminal. Electricity, decomposed steam, spheroidal state of water, the development of hydrogen, and superheated water, are among the various explanations which daily appear. That

these explanations are not confined entirely to the layman is shown from the following, taken from a little book on "The Steam Boiler," published in the early part of the last century: "Few people are able to believe that steam boilers have actually burst with a fair pressure of steam, however great that may be, and operative boiler makers are staunch advocates that it is gas electricity that is concerned in tearing the boiler to pieces." We will not attempt to say that these various forces do not produce boiler explosions, but refer the reader to Shock, Thurston, Colburn and other authorities upon the subject.

An ordinary horizontal tubular boiler under an absolute pressure of 115 pounds to the square inch, containing 14,560 pounds of water, has stored in it 1,872,416 B. T. U., the mechanical equivalent of which, representing the maximum effect, is 1,460,484,480 ft. lbs. It will be shown later that 8.75 per cent of this, or 127,938,720 foot pounds are available for external work, and, remembering that a horse power is the equivalent of 550 foot pounds per second, we see that if this work were expended in one second, there would be developed 232,615 horse power; or, to put it in another way, if our boiler weighed 8 tons, there would be sufficient energy to lift it 7,996 feet, equal to 1½ miles, into the air. Considering these facts, we need seek no further for an explanation of its explosive possibilities, and can best spend our time in ascertaining the manner in which this force is liberated, and what part of it is available for external work.

While the available energy in a unit weight of steam is much greater than in a unit weight of water of the same temperature, the lower density of the former and the smaller amount in a steam boiler makes its energy of comparatively little importance, and we will confine ourselves to the problem of computing the energy available for external work in one pound of water under an absolute pressure of 115 lbs., when expanding to an absolute pressure of 14.7 lbs. per square inch.

The following notation will be used:

t = Any temperature Fahrenheit.

T = t plus 461° = Absolute temperature.

h = Quantity of heat to raise a pound of water from 32° to t .

p = Absolute pressure in pounds per square inch.

L = Quantity of heat to evaporate a pound of water at any given temperature.

H = Quantity of heat to raise 1 pound of water from 32° to t and to evaporate it at that temperature.

x = Number of pounds of dry steam in 1 pound of a mixture of steam and water.

V = Specific volume of dry steam.

J = Mechanical equivalent of heat = 780 ft. lbs.

The subscripts 1 and 2 relate to the initial and final states.

By the expansion of one pound of water under the conditions given above, there will be liberated (h_1—h_2) B. T. U., or 309.5—180.9 = 128.6 B. T. U., which have a mechanical equivalent of 128.6 x 780 = 100,308 ft. lbs. This energy will be expended in internal and external work; i. e., in evaporating a portion of the water, and by accelerating pieces of boiler plate, the air and whatever opposes the expansion of the steam. Let us first obtain an expression for the amount of heat to be used in internal work. Taking the adiabatic equation

$$\frac{X_1 L_1}{T_1} + \log_e T_1 = \frac{X_2 L_2}{T_2} + \log_e T_2$$

substituting for x_1 its value 0, and solving for $x_2 L_2$, we have

$$X_2 L_2 = T_2 (\log_e T_1 - \log_e T_2) = T_2 \left(\log_e \frac{T_1}{T_2}\right)$$ and substituting the proper numerical quantities, we have $x_2 L_2 = 673 \times .1703 = 114.61$ B. T. U., and we obtain 114.61 x 780 = 89395.80 ft. lbs. as the internal work. This figure is based upon an average specific heat for water of unity, which is not strictly accurate, the value between 337° and 212° being more nearly 1.024, and multiplying the quantity just obtained by this figure, it is increased to 91,521 ft. lbs. The energy available for external work is clearly the difference between the total amount and the internal work, or 100308—91521 = 8787 ft. lbs.

It is interesting to note the amount of water that is vaporized by the expansion. Solving the adiabatic equation for x and making $x_1 = 0$ we have $x_2 = .1186$, or we have after explosion about 12 per cent of the mass as steam and 88 per cent water.

In our boiler explosion the ratio of the heat transformed into external work to the heat available is $\frac{8787}{100308} = .0875$, or 8.75 per cent, which is, of course, very high; per pound of the working substance, however, it is very low, as such an engine would require per horse power per hour $\frac{1980000}{8787} = 225.3$ pounds of water.

From the above it may be seen that to liberate the explosive energy in a boiler we must suppose the boiler to rupture, and by this means to permit the pressure on the water to be suddenly reduced. This initial rupture is due to defective design, poor construction, bad material, improper treatment of the boiler when in operation, deterioration, or to a combination of two or more of these causes. All ruptures do not cause violent explosions; some are of a local nature, extending over a small area, or include an area upon the rigidity of which the strength of the structure as a whole does not depend. As an example of this we may cite a rupture in a water leg, which as a general thing does not produce great damage, while a tear in the cylindrical

part of the shell is almost invariably followed by the most disastrous results. A rupture, then, of such a nature that it deprives the structure of an essential support, and of an area sufficient to permit the discharge of a considerable mass of steam and water, will, by thus rendering available for external work, a portion of the enormous energy confined in the boiler, produce results which rival in their destructive effect any modern explosive.

Having considered the nature and magnitude of the available force and the conditions necessary for its liberation, let us take up their sequence and show what may be called the method of the explosion, and for this purpose we can do no better than to give in his own words what Colburn calls "The distinctive and consecutive operations into which a boiler explosion, although practically instantaneous, may be resolved."

"The rupture under hardly, if any, more than the ordinary working pressure of a defective portion of the shell of the boiler, a portion not much, if at all, below the water line.

"The escape of the free steam from the steam-chamber, and the consequent removal of a considerable part of the pressure upon the water, before the contained heat can overcome its inertia and permit the disengagement of additional steam.

"The projection of steam, combined as it necessarily must be with the water, with great velocity and through a greater or less space, upon the upper sides of the shell of the boiler, which is forced completely open, and perhaps broken into pieces.

"The subsequent disengagement of a large quantity of steam from the heated water now no longer confined within the boiler, and the consequent projection of the already separated parts of the boiler to a greater or less distance."

When all this has been said, and all computations have been made, we have been through a more or less interesting review of our elementary thermodynamics, and have in no great measure upset the equanimity of the average boiler that wants to explode, for in the formulæ given one factor has been omitted, and this is X, which, always representing an unknown quantity, in this case stands for the man-behind-the-pump. Considering this factor, the safety of the steam boiler is not amenable to strict mathematical analysis, and, like the human mind, cannot always be relied upon to do what it should.

THE DESIGN OF SWITCHBOARDS FOR ISOLATED PLANTS.

ARTHUR L. ABBOTT, E. E., '97.

It is a well recognized fact that an orderly, attractive, systematically arranged plant is conducive to the highest efficiency of the operating force; and if this is true of the plant in general, it is to a still greater degree true of the switchboard. As the switchboard is the center of control and distribution for all electrical energy generated, so also it is to a certain extent the center of inspiration for the operatives. The subject of switchboard design therefore merits considerable attention from the engineer. As this entire subject would require a large volume for its adequate discussion, this paper has been confined to a comparatively small branch: that of direct current isolated plant switchboards. No diagrams of connections are included, as the ordinary machine connections are matters of common engineering knowledge on which an abundance of data is available, and furthermore, the connections of all the electrical apparatus should be considered as a part of the design of the plant in general rather than of the switchboard. The subject is not new and has had no recent striking developments. It is intended to present a working outline and summary of good practice, with as much detailed information as space allows.

It is presumed that before taking up the design of a board, the functions of the board have been decided upon: the number and size of generators to be controlled, number and capacity of feeders to be supplied, etc.

Location:—A rough estimate having been made of the size of the board, the location should first be decided on, together with the location of all generator leads and feeders leading to the board, and then the board designed to fit its position in the plant. Only two general rules can be given for the location:—The board should be so placed as to be in plain sight and easy of access from the engines and generators, and it must be placed far enough from the wall to give a comfortable working space in the rear. Five feet is a minimum for boards of medium size, and this should be increased for large boards with massive bus bar work projecting some distance from the marble.

General Form:—For very small plants, in which one generator of small size supplies from one to three or four feeders, the switchboard apparatus is usually all grouped together on one panel. The same general rules will apply as to a larger board, the

problems being much simpler, as the number of parts is less and the conductors are of small cross section. Larger boards are built up of panels. These are for the most part generator and feeder panels. Some boards contain also a total output panel, and other special panels are used as may be required, as for storage batteries, etc. The most rational arrangement of a board containing several panels is to place generator panels at one end and feeder panels at the other end, with the total output panel, if there be one, in the middle. This simplifies the bus bar work, as the energy is carried in one general direction clear across the board. It also allows for enlargement in the best possible way, as generator or feeder panels may be added at the ends without change in the original board. Such a board is however unsymmetrical. In case there is no total output panel, perfect symmetry may be obtained by placing an equal number of feeder panels at each end and the generator panels in the middle. A small number of totalizing instruments may be divided among the feeder panels so as to preserve the symmetry. The required capacities of many isolated plants can be determined very closely in the original design, and in such cases no room need be provided for the extension of the board.

Generator Panels:—A generator panel will usually contain a circuit breaker, a generator switch, a field rheostat, ground detector lamps, a pilot lamp and an ammeter, with perhaps a voltmeter switch. Behind the board the generator leads will come to the bottom of the panel, and feed through the circuit breaker to the generator switch. The circuit breaker will then naturally be placed at the bottom, with the switch above it. The voltmeter switch and rheostat, or at least the rheostat hand wheel, will be placed well up on the panel so as to be within easy reach of the operator, without stooping.

Feeder Panels:—Feeder panels may control any convenient number of feeders. They will, as a rule, contain nothing but the feeder switches and fuses or circuit breakers, surmounted by certain instruments. Circuit breakers are seldom used on lighting feeders. Their use may be advisable on power feeders when the conditions are such that occasional short circuits or very heavy overloads may be expected. In such a case the switch may well be dispensed with if the "double arm" type of circuit breaker is used. All feeders not supplied with circuit breakers will, of course, be protected by fuses. The latter, if mounted on the front of the board, must be of the enclosed type. Fuses of any type are better mounted on small slate or marble panels behind the board.

Special Panels:—No specific rules can be laid down for these, the design necessarily depending on the use of the panel. As

in all switchboard work, different pieces of apparatus that are co-related should be so grouped together that their relation to each other will, as far as possible, be apparent from their position, and it must be borne in mind that simplicity of connections behind the board is of equal importance with a tasteful arrangement of the front.

Switches:—The style of switch commonly known as the "all copper, single break" has become almost a standard for switchboard work up to 300 volts. Such a switch will break considerably more than its rated current at its rated voltage without arcing across, therefore the addition of the two extra contact posts and clips in the double-break switch would seem a useless complication. It is the strongest and cheapest type of switch made, and the neatest and most mechanical in appearance. All switches should be mechanically strong and rigid, and strictly in accordance with the Fire Underwriters' requirements as to spacings, contact surfaces and general construction. The generator switch may be a triple pole switch or may be divided into three single pole switches, or one single pole switch and one double pole. In throwing in a new generator, either of the two latter arrangements may be used to pass current from the bus bars through the series field of the new machine by means of one main lead and the equalizer, before connecting the other lead. This is of some advantage in operating heavily over-compounded machines. As isolated plant dynamos are usually not over-compounded, or very slightly so, a three-pole generator switch is preferable, except when the current to be handled exceeds 1,500 or 2,000 amperes, when three single pole switches should be used to facilitate handling. A full discussion of this question may be found in the American Electrician for January, 1901, by Alton D. Adams. An interesting departure from ordinary practice is described by Chas. E. Knox in the American Electrician for February, 1903. In order to save the cost of very heavy equalizer cables from machines to switchboard, a motor-operated three-pole switch is placed near the generator and controlled by a pilot switch on the board. It is difficult to see, however, any gain proportionate to the expense and complication, over the old method of placing the equalizer switch on a pedestal near the machine, with the main switches on the board.

Circuit Breakers:—Circuit breakers may be of the knife-blade contact type up to 500 or 600 amperes capacity. In larger sizes this type becomes too difficult to operate, owing to the strength of spring required to insure positive opening. In the laminated contact type this difficulty is obviated, hence it is much better for the larger sizes. It is preferable for all sizes, but is more expensive. A fault common to most circuit breakers of the latter

type is lack of a suitable buffer to deaden the blow of the moving parts in opening. In the writer's experience with circuit breakers of a well known make, this blow has been strong enough to impart a decided shock to the whole switch board, releasing the triggers of other circuit breakers and causing them to open. Any such vibration of the board is also likely to injure the jewels in instruments.

Rheostats:—Some form of enamel rheostat will of course be used. There is practically little difference between several of the best makes. The builder of the dynamos should furnish data as to ohms resistance required and strength of field current.

Instruments:—In the choice of instruments—indicating ammeters and voltmeters—it is desirable to secure an instrument that is accurate, has a large uniformly divided scale, is nearly dead beat and presents a good appearance. The latter point is sadly neglected by the makers of some of the best instruments. Instruments of the illuminated dial type are decidedly preferable. The position of the pointer is very distinct and there is no source of light visible to blind the attendant.

Lighting:—No incandescent lamps for lighting should be placed on the switchboard proper, but the light should be evenly diffused from some outside source which is out of the attendant's line of vision when taking readings. With low ceilings, very good results may be obtained by placing large Holophane "domes" or hemispheres on the ceiling and a few feet in front of the board, spaced ten to twelve feet apart, and each containing two 32 c. p. lamps.

Pilot and Ground Detector Lamps:—To avoid the glare of a lamp burning at full candle power on the board, the lamp used for lighting the illuminated dial of the generator ammeter may also be used as the generator pilot lamp. The only objection to this plan is the dead appearance of an ammeter not in use. Another plan, slightly more expensive, is to mount the pilot lamp behind a circular piece of ruby glass set in a hole cut in the switchboard panel. Ground detector lamps are usually mounted on the front of the board in keyless receptacles, and may be placed on all generator panels, though one set for each set of bus bars is all that is necessary. If six or eight candle power ruby lamps are used, the appearance will be much better than that of larger ordinary lamps. The ground connection is sometimes made through a push button, and sometimes made permanent.

Voltmeter Switch:—The best voltmeter switch is one made on a porcelain base, with a form of contacts which are not too sensitive, that is, which will not fail to make contact even though the mechanism may be a trifle worn and out of adjustment. If fiber is used for the base, the screws holding the parts together are

liable to require tightening repeatedly, for in a hot, dry place, fiber seems to continue to shrink indefinitely.

Materials for Panels:—The only materials used for the board itself are marble and marbleized or enameled slate. The insulating properties of marble and slate are equally good for low potentials such as are ordinarily used in isolated plants. Slate is cheaper, stronger, much softer, hence much more easily drilled than marble, and the appearance of the best marbleized slate is certainly equal to that of any marble. The marbleizing, or finish, is unfortunately, not permanent, as it becomes scratched very easily and hence deteriorates with natural wear and tear. It is there-

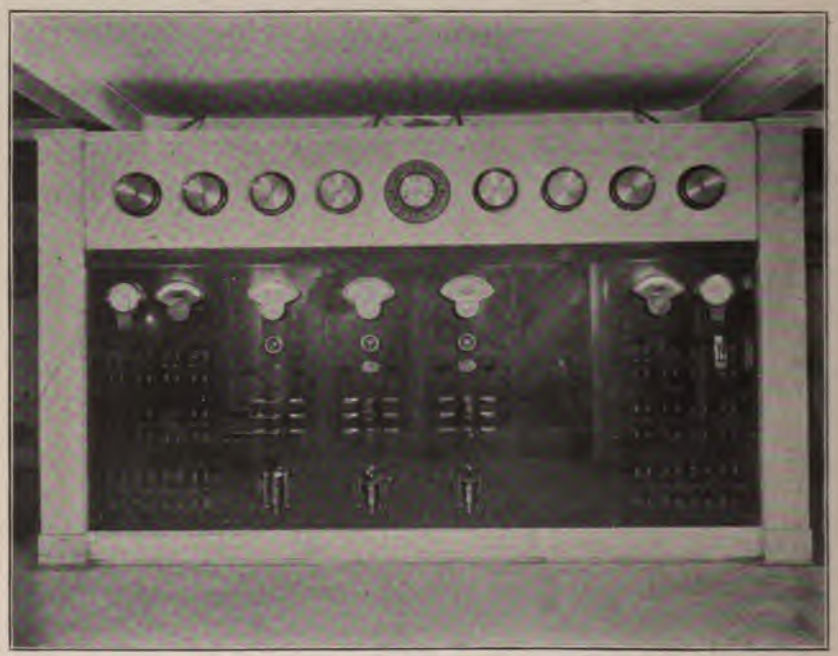

Figure 1

fore seldom used in the better class of plants. Panels of either slate or marble may be obtained in almost any desired size. The thickness may vary somewhat according to size and method of supporting the panels, and according to the size and type of switches and circuit breakers. It is seldom less than one and one-half inches and never exceeds two inches.

Frame:—The supporting frame is usually built up of angle or tee verticals joined to a horizontal angle or channel at top and bottom. A good design, heavy enough for most boards of medium size, would be a vertical 2½"x3"x⅜" tee centered on the dividing line between each two panels, a vertical 2"x2½"x⅜"

angle at each end, the whole joined by means of small angle pieces to a horizontal 2″x2½″x¼″ angle at top and bottom with a ¾ inch pipe brace from the top of each vertical tee and angle back to the wall. If the marble is made of ample strength to stand all strains from switches and circuit breakers when supported only at top and bottom, it may be desirable to allow more room for bus bar work by omitting some of the verticals. In such case the remainder of the steel work must be increased in weight. The frame should be set on a shallow foundation of masonry or concrete if possible, to insure absolute freedom from vibration, which is injurious to the instruments.

Carrying Capacities of Bus Bars:—Good authority can be found for making the current density in copper bus bars any-

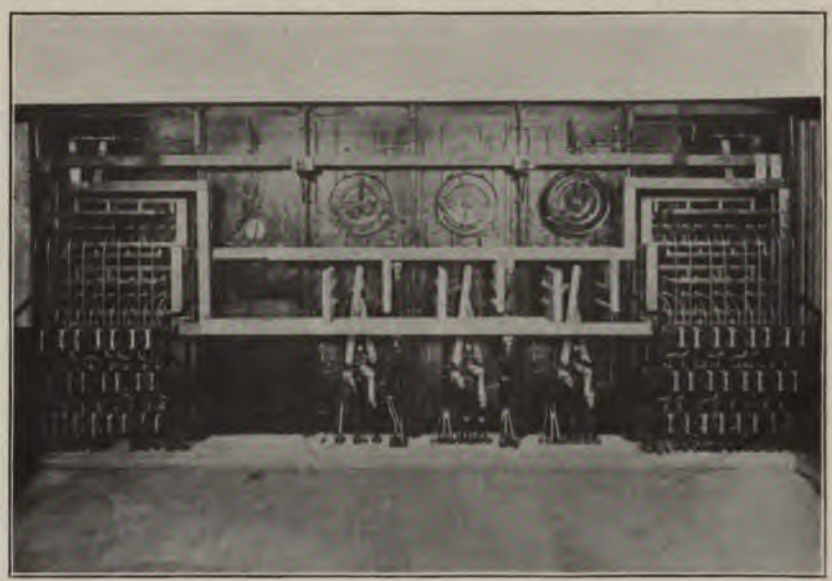

Figure 2

where from 600 to 1,600 amperes per square inch of sectional area. Albert B. Herrick gives a table (Modern Switchboards, p. 34; Electric Railway Handbook, p. 258; Foster, Electrical Engineer's Handbook, p. 587) which gives the current which he states "can be carried economically by copper bus bars in ordinary central station practice where the load factor is not greater than fifty per cent." In this table the current density varies from 1,200 amperes per square inch for a bar 2 inch x ½ inch to 1,700 amperes for a bar 1 inch x ¼ inch.

In considering the question of current density there are two points to be investigated, the heating of the conductor and the loss of energy so expended. If only the final temperature of the bar is to be considered, it is somewhat difficult to fix the limit. In

the best practice a rise of 35° to 40° C. above the surrounding air is a standard for the windings of electrical machinery. It would appear that the limiting temperature might be fixed much higher for bus bar work supported on material which cannot deteriorate with high temperature.

In the American Electrician for Feb., 1902, are given tables showing sectional areas and perimeters of bars required to ensure a temperature rise of 20° F., also for a rise of 30° F. These tables are based on values of .036 watt and .058 watt radiated per square inch for a temperature rise of 20° and 30° respectively, which figures agree quite closely with those obtained from Kennelly's formula for radiation from round copper conductors. Taking values from the above tables for some common sizes, we find that for a rise of 30° F., above a room temperature of 90°, a bar 1 inch x ¼ inch will carry 875 amperes per square inch; a bar 2½ inch x ¼ inch will carry 800 amperes per square inch; and a bar 3 inch x ⅜ inch will carry 675 amperes per square inch.

That size of bar will be the most economical in which the annual cost of the lost energy equals the annual interest on the cost of the bar.

Let I = most economical current per sq. in., bar to be figured on basis of maximum current.

Sectional area of bar = 1 sq in.

Length of bar = 1 ft.

Weight of bar = 3.89 lbs.

Resistance of bar = .00000897 at 90° F.

a = cost of energy per K. W. hour.

b = cost of bar erected per lb.

c — a factor such that I c = square root of the mean square of the ordinates of the load curve, or in other words I c = square root of the average of the squares of all values of the current during one year. It is evident that the value of c for any given case can only be determined from an assumed load curve, or better from two curves, one representing daily current variations for winter and the other for summer.

Then cost of energy annually lost in bar is

$$\frac{(Ic)^2 \times .00000897}{1000} \times 8760 \times a \qquad (1)$$

Annual interest on cost of bar at 6% is

$$3.89 \times b \times .06. \qquad (2)$$

Equating (1) and (2)

$$\frac{(Ic)^2 \times .00000897 \times 8760 \times a}{1000} = 3.89 \times b \times .06.$$

$$I = 54.5 \frac{1}{c} \sqrt{\frac{b}{a}} \qquad (3)$$

For a = $.03.

b = $.40.

c = .27.

I = 737 amperes.

It is believed that these figures are a fair average for isolated plants of medium size in which the main part of the load is lighting. The value of the factor c was obtained as indicated above for such a plant, of 20% of the maximum current flowing steadily for one year would give a total K. W. hour output equal to that shown by the curves, while 27% of the maximum current flowing steadily for one year would give the same total K. W. hours loss in the bus bars at the varying loads shown by the curves. It is to be noted that in equation (3) I varies inversely as the first power of c, the load factor, while only the square roots of

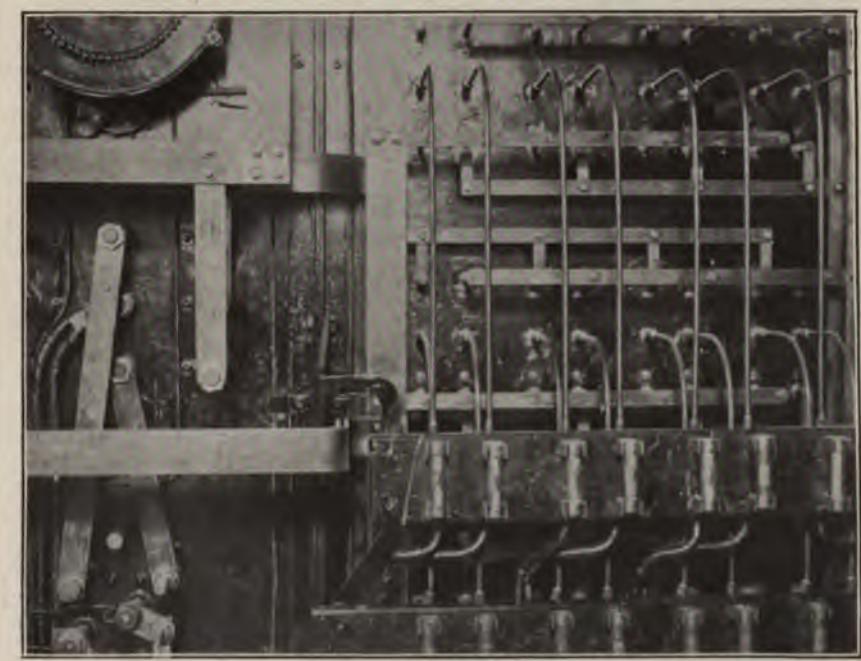

Figure 3

a and b appear. A greater degree of accuracy is therefore necessary in determining the load factor than the other two quantities.

It would seem proper to base the current density on considerations of economy rather than of heating of the conductor, making the above calculation for any given case. It will be found, however, that considerable variation from the current density indicated by the formula will make a difference of only a few dollars a year in cost of operation, except in large plants. 750 amperes per square inch is a good value for general use.

General Layout:—To design a well proportioned, attractive looking board the designer will have to depend almost entirely

upon his own good tastes and sense of proportion; very little advice can be given. For the sake of appearance, it is well to maintain an unbroken line of instruments clear across the top of the board, if possible. One or two voltmeters are often placed on a swinging bracket at one end of the board. This is highly satisfactory in operation, as the instruments are in full view of the operator from any position in front of the board. It is not practicable, however, with many forms of ornamental frame or setting. The exact location of the apparatus on the front of the board must be taken up simultaneously with the layout of connections on the back. It is no great achievement to design a board which will present a good appearance from the front, if the work on the back is left out of consideration. In all the main bus bar work, there should be ample spacing between parts of opposite polarity; with standard apparatus, it will be found difficult to make this distance greater than two inches for 250 volt work. Two inches may be taken as a minimum, while a greater distance would probably be better. The bus bars and connections to switch studs will, of course, consist entirely of copper bars. At joints the surface should be fitted perfectly and always secured by iron bolts. For joining large bars, several small bolts may be used or one large bolt with two heavy machined cast iron washers to distribute the pressure. Connections to switch studs are made by clamping the bar between two nuts. The "straight out" method of making connections should be used wherever practicable. This method saves copper, eliminates a considerable number of joints, and saves much labor, as there are no bent connection pieces. Bends should be avoided wherever possible, as they are expensive, and become difficult to make in the larger sizes of bars. Where their use is unavoidable, it is well to reduce the size of large bars by using two or more in multiple. Switch studs may be extended for straight out connections by using continuously threaded copper rods cut to the required length and joined to the stud by a long threaded split sleeve or coupling clamped with two or more screws. A better piece of work may be done, if the work is previously designed in detail as it should be, by using switches with studs made to order, the required length. These may be obtained from any maker at no great extra cost.

It is generally not difficult to carry the connections from generator switches to feeder switches. From this point on, in boards controlling a large number of feeders, the design is more difficult, and is often neglected entirely. It being first determined whether the feeders are to leave the board at the top, bottom, or both, the fuse boards, if used, should be so placed that connections either of copper bar or rod can be carried to the fuse terminals, and

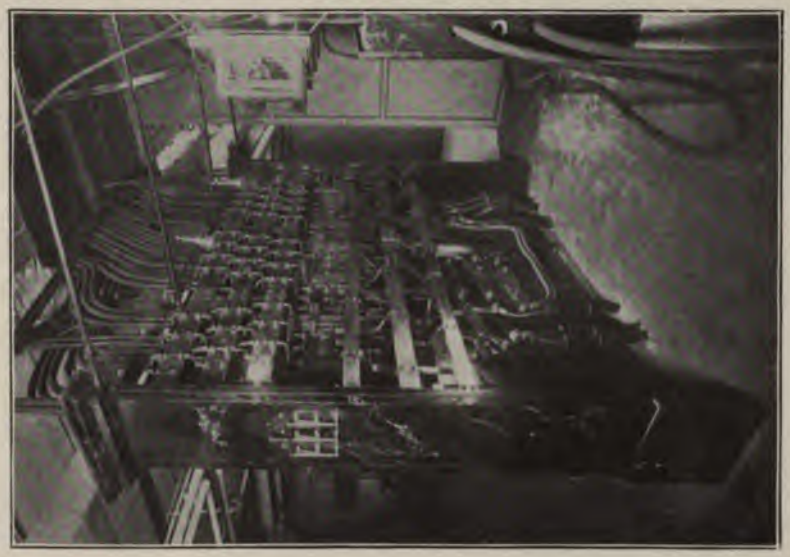

Figure 5

Figure 4

from the latter the feeder cables can be run, in some symmetrical and workmanlike manner. The fuses must be accessible, and there must be no loose cables looped around to bring them to the proper terminals. Many boards are built with apparently no thought whatever having been given to the connection of feeders, with the result that what seemed a fine piece of work in the shop, finally appears a confused mass of conductors, put together without foresight or design.

Another matter which is often slighted is the proper running of the small connections for instruments, pilot lamps, ground detectors, etc. On the back of each generator panel should be placed a small fuse block, connected to the switchboard side of the circuit breaker. From this are taken connections to the voltmeter switches, pilot lamps, and ground detector lamps. All these connections, as well as the ammeter cords and any other small wires, should be run in some systematic and workmanlike manner. One method is to secure all such wires to the back of the board by small fiber or metal cleats, fastened to the marble by small expansion bolts or bolts set in plaster paris or lead. On large, massive boards these connections may be carried in a complete system of iron conduit with outlet boxes installed directly on the back of the marble. For boards of small or medium size this construction would be too clumsy in appearance and would necessitate carrying all bus bar work three or four inches farther out from the board than would otherwise be done.

Figures 1 and 2 show front and rear views of a typical board in a plant which has a considerable load of motors as well as lighting. The board contains three generator and two feeder panels, with a blank panel for an additional generator. The total capacity of the plant as installed is 200 K. W. at 220 volts. The bus bar work is proportioned for a current density of 600 amperes per square inch. There are two sets of bus bars, one for light and one for power, with a three-pole switch on an end panel (not shown) to connect the two sets of bus bars in multiple if desired. All switches are double throw, so that any generator or feeder can be thrown on either set of busses. Fig. 3 is a detail view of part of the work on the rear, showing connections from main busses to feeder switches, also feeder fuses and their connection to feeders and switches. In Fig. 2 the eight small wires stretched across the top of the board between two blocks of slate, form what might be termed a set of potential busses for four generators. All eight wires are tapped to both volt meter switches, and the respective pairs are fed from small fuse blocks on the generator panels. Since the photograph was made, name plates have been added showing the feeder controlled by each switch. The panels are black marble. The combination with a gauge board is not to

be commended from any point of view, but was unavoidable in this case. The artistic effect of the board as a whole is somewhat marred by the poor design of the surrounding frame and gauge board of white marble.

Figures 4 and 5 show a feeder board installed in a large office building having no generating plant, the board being adapted for connection to generator panels, in a case a plant is installed. The board is fed from the Edison three-wire system through two single-pole circuit breakers and a four-pole "break-down" or throw-over switch. All feeder switches are three-pole, the feeders being three-wire with the neutral double the size of the outers. All feeders leave the board at the top. The three fuse boards shown in the rear view behind each panel contain respectively positive, neutral, and negative fuses, all terminals and fuses on one board being of the same polarity. Open fuses are used and it is a fact of some interest that none of the original fuses on the board have blown in over a year of service, while the circuit breakers have repeatedly opened, though set for a current much exceeding the rated capacity of any of the fuses. Connections from feeder switches to fuses are made by means of soft drawn bare copper wire bent to the required shape and then taped and painted, care also being taken to keep opposite polarities separated a safe distance.

It was intended to show examples illustrating several different types of isolated plant switchboards, but unfortunately the material was not at hand. The deficiency in this respect can however be well supplied by reference to the files of the technical press.

TRAINING OF THE SPECIAL APPRENTICE.

(The following article is a summary of the discussion of a paper on the above topic presented by Mr. T. A. Foque at the December meeting in St. Paul of the Northwest Railway Club. Its special reference to the technical graduate makes it of interest to University students in the engineering courses.)

The progress and development of railroad engineering has in the past been due largely to the genius and untiring energy of men who without any special technical education have instructed themselves in the school of experience. This method is still open, but the increasing requirements of transportation demand from those who enter the railroad service a knowledge of the principles of engineering which can be more readily obtained by perusal of the courses in railroad mechanical engineering offered by the various technical schools throughout the country.

The college graduate is therefore the one who is here considered, the man who has already spent four years in technical training and who presumably has acquired a certain amount of development, a certain amount of mental training and a certain amount of knowledge which fits him more or less for his railroad engineering work.

Such a one is to be trained for railway service and as soon as possible made part of the organization. This instruction will consist perhaps of one year in the shop on machines and one year on the floor, meaning erecting and work in general that relates to the construction and erection of the locomotive, a large part of which is best obtained in the round house. Boys when they go through the college machine shops are not machinists—they do not claim to be and it is folly for any one to suppose that they are; sometimes we find otherwise intelligent men who have presumed that the college boy having spent eight hours or possibly ten hours a week for two years or three years at most, is a finished artisan or mechanic: the college graduate is compared with the boy who entered the machine shop or manufacturing concern at the end of his grammar school or high school work, and has now been four years or more in the shop and has become a skilled journeyman, and because college boys cannot hold their own in practical shop work alongside of these men they think college shop training a failure. It is not a failure at all. Considering that the college boy does not get one-third as many hours in the whole course as the shop boy gets in one year it is wonderful what he has acquired.

If an apprentice wants to achieve the greatest measure of suc-

cess he should first obtain a practical knowledge of the details of his chosen line.

Two years in the machine shop after he has graduated ought to be sufficient. If it is to be railway work let it be in a railroad shop; manufacturing of machine tools, let it be in such a shop; manufacturing of pumps, let it be in a pump factory; but let him get that foundation in the practical work in which he is going to spend his life. In the present case we are considering such a boy who spends two years in a railroad shop. In this time he learns a great deal about locomotive engineering. He sees what is going on in the shop and keeps in touch with it.

Give him six months in the drawing room when he has gone through the shop and round house. During this time frequent trips about the shop will make him familiar with many details. No opportunity for improving shop methods or cheapening the cost of production should be overlooked. The keen student will also note a good foreman, and by cultivating a close acquaintance learn much about the handling of men. In the selection of new machinery and its location as well as the rearrangement of old, the apprentice should be considered.

The installation of new machines should be carefully watched by the special apprentice during his term in the drawing room, so that he may see the practical results of his work and possible difficulties met with in the shop. In the designing of new equipment special opportunities are offered him for an expression of ideas.

After he has been in the draughting rooms give him six months of testing work. Let him go out on a locomotive and take the weights of coal and water, the draw bar pull, and the tonnage, or any other line of road testing. Let him be put in a laboratory if there is one to test materials, iron and steel, bronzes, bearing metals, and so forth. If he is a man who has had some knowledge of chemistry let him assist in analyzing paints, or feed waters, and in work of that kind. Although he does not aim to be a chemist, if he had been fundamentally trained, he can be used to good advantage along these various lines, and the knowledge thus obtained will be of great value to him and to the road later on.

It is not always possible nor is it always desirable to wait until the latter part of the third year before the special apprentice is put on testing; he should be assigned to it whenever there is such work to be done if there are no other men available. If there is need for such a man to make coal tests or do any other testing that may be demanded let him go out and do it. He is interested and qualified; he has been trained to do just this sort of thing. He is a keen observer, knows how to correlate results and to make a suitable report on the work that is being investigated.

On a large road the step from the testing department to mechanical engineer's office is a short one; on a smaller one the special apprentice may readily pass from the drawing room to the position of assistant superintendent in the mechanical department.

Some roads offer a four years' course, two years of which are spent in the drawing room, but a three years' course six months of which are spent in drawing and six months in testing is often to be preferred. When we consider that a man has already spent four years in the high school and four years in college why spend four years more, making it twelve years after he leaves the grammar school before he is good for anything? Now practically all the roads throughout the country know that a boy is good for something after he has been there a year, after two years he is worth a great deal more, and after three years we find a good many mechanical engineering graduates occupying responsible positions.

Now comes the matter of pay; for the first year 15 cents per hour is about all the average boy is worth. That is a fair proportion for the first year or first six months perhaps, but a great many boys are worth a good deal more than that after they get located and accustomed to their surroundings. It is a pretty poor boy that is not worth more than that after six months' service. When it comes to the next year 20 cents per hour is good for the average man the first half year. He is learning and oftentimes demands a great deal of attention from men whose time is very valuable. But when it goes beyond that let the ability of the man set the salary or pay that is to be offered. The trouble today is to get young fellows to do this work. The demand for such technical graduates is so great that it can not possibly be filled. Such men cannot be kept at 22½ cents per hour the third year and certainly not the fourth.

It is to the interest of any road to develop the special apprentice, but it cannot secure good material nor retain good men unless it makes them reasonably contented and this cannot be secured with too long a course or too meager a compensation.

To the special apprentice himself it might be said that the railway service while offering unlimited possibilities to a young man and especially to him who has been educated for that service, demands untiring effort to do well, a mastery of every detail, and above all unswerving faithfulness to duty. With an army of men about him looking for advancement, opportunities must not be allowed to pass or disappointments to discourage.

STUDY OF THE COST OF ENGINEERING CONSTRUCTION.

L. E. ASHBAUGH, C. E., '00.

Two general questions appeal to the engineer on taking up any design and construction. The first one is usually of this nature, how shall the work be done, what materials will be used, what design adopted, in what order shall different parts of the work be prosecuted? The answer to these questions will frequently depend upon the results of the second general question, how much will it cost what is the relative expense of the different plans proposed, will the result secured by the best plan justify the expense over some cheaper plan, how can a saving be made without reducing efficiency?

This subject suggests itself, not because of any special knowledge of the same on the part of the author, but, on the contrary, because he has come face to face with just such questions, and with little preparation for their solution. While a student at the University of Minnesota and during the few years since graduation, some interesting illustrations of this subject have been noticed. They are mentioned, not for their value as engineering data, but that they might suggest to the present student some means of obtaining such important information.

On the construction of some concrete piers, it was noted that in footing courses, where large pieces of rock were used for filler, for each cubic yard of concrete in place, 0.77 barrels of cement were used for abutments with foundation in dry soil, and 0.90 barrels for channel piers on piling in quick sand. The time required to put in such work was 2.44 hours of labor per cubic yard for the dry foundation, and 6.58 hours for the wet foundation. After laying the footing to the channel piers, each cubic yard of concrete in the next course was found to require only 0.61 barrels of cement and 2.55 hours of labor, while the next course in the abutment required 0.84 barrels of cement and 2.16 hours of labor, the great difference in results being caused by the pier being of so much greater area, that more filler rock could be used, while at the abutment there was no trouble and expense occasioned by water. Above the surface of the ground no filler rock was used, and a 3-inch facing was made. There was then required from 1.15 to 1.25 barrels of cement to each cubic yard of concrete, besides 4.00 barrels for each cubic yard of facing, and the time required was 3.06 hours when the concrete could be shoveled directly into the forms as at the abut-

ment, 3.70 hours for the first 12 feet of the pier above ground, and 7.22 hours for that part of the pier from 12 to 26 feet above ground. The average time for each structure was 2.66 hours per cubic yard for the abutment of about 150 cubic yards, 4.33 hours for the pier of about 330 cubic yards, while for a small pedestal of about 36 cubic yards, 18 feet high, standing 9 feet above ground, 4.53 hours were required. The cement averaged 1.11 barrels per cubic yard for the abutment, 0.97 barrels for the pier, and 1.33 barrels for the pedestal.

M. & ST. L. R. R.

Summary of Data collected by engineer during the construction of the Concrete Piers for the Viaduct over the Little Sioux River, at Sioux Rapids, Iowa, 1899.

Part	Ratio of Ingred'nts	Volume Cu. Yds.	Cement Used, Bbls	Ratio Bbls. Per Yd.	Time—Hours Boss	Men	Carp.	Time Ratio Hrs. Pr.Yd. For Men
NORTH ABUTMENT								
Footing	1:3:5½	27.08	20.75	0.77	7	66	Carpenters (Estimated)	2.44
Neat Work Below Ground	1:3:5½	48.15	40.50	0.84	12½	104		2.16
Neat Work Ab've Gr Body	1:2½:4½	70.23	80.75	1.15	25	234		3.06
Neat Work Ab've Gr. Facing	1:1	6.41	26.25	4.10				
Total		151.87	168.25	1.11	54½	404	200	2.66
"One-man rock" used below ground. Facing 3 in. thick on all exposed parts								
CHANNEL PIER—NO. 2.								
Footing	1:3:5-6	35.76	32.00	0 90	25	235		6.58
Neat Work 933.00 to 941.75	1:3:6	107 84	65.50	0.61	16	275		2.55
	1:2½:5	111.73	81.50	0 73				
Neat Work 941.75 to 955.00	1:1	9.00	36.00	4.00	31	446		3.70
	1:2½:5	56.75	71.50	1.26				
Neat Work 955.00 to 968.71	1:1	7.85	33.00	4.20	28	467		7.22
Total.....		328.93	319 50	0.97	100	1423	260	4.33
"One-man rock" used very freely below ground—El. 941.75. Its use was continued to El. 955.00. Facing 3-inch, as above.								
PEDESTALS—BENT 35.								
Total.....		36.46	48.50	1.33	23	165		4.53
Height 18.15 ft. Ht. Above Gr. 9 0 ft.								

It is estimated that, on north abutment, there were used 25.16 Cu. Yds. cement, 64.61 Cu. Yds. sand, 115.26 Cu. Yds. Crushed Rock (loose) and 22.6 Cu. Yds. "one man rock" (solid).

On Pier No. 2 there were used 51.6 Cu. Yds. "one man rock" (solid).

L. E. ASHBAUGH, Engineer on Viaduct.

T. G. BOLSTAD, Res. Engineer.

Attention is called to the great difference in time expense in the abutment and pedestal noted, both in the same foundation

soil, and on the same hillside, the smaller structure requiring nearly double the time. Cement expense shows about 20 per cent difference in favor of the larger structure. The large high channel pier on wet foundation shows greater expense for labor, but smaller expense for cement than does the abutment.

On small railroad construction the following records were taken: In clay soil, wet and sticky, borrowing along side to make a fill 5 feet high, each team was able to get out only 33 cubic yards per day. At a mile distant, the same teams when working in sandy gravel on borrow for an embankment 7 feet high, got out 75 cubic yards per day, the latter being dressed off as per specifications, while the clay bank was left incomplete. Eight cents was paid in each case. Another man, moving west with a prairie schooner, worked with his two teams and two little boys 18 days, building base to a 16 ft. embankment by borrowing along side, and put in 57 cubic yards per day for each team. Small slip scrapers were used in above work. A sub-contractor, taking one mile of embankment of 3 to 8 feet fill, with borrow and short haul from cuts, got out about 80 cubic yards for each team, and dressed the bank. He received ten cents per yard, and used large slips and wheel scrapers. On small pieces of work on another road, in connection with grade revisions and side track extensions, where soil is heavy and the haul was frequently 500 feet and over, teams were often not able to make wages at twenty-five cents per cubic yard. Excavations of pits for bridge abutments and piers usually cost from fifty cents to one dollar per cubic yard, while the contract price is frequently placed at twenty-five cents.

The data given may not represent average conditions, nor either extreme. It can not be supposed by any student engineer during his first few years in the field that the results of data which he collects will hold in all cases, or perhaps in any other work than that from which the data was secured. But he will be able to make a fair estimate of cost of work similar to that before noted. Data thus collected may be made of great value. One is able to use data of his own to much better advantage than that found in text-books, reports, etc., because he knows the exact conditions under which the work was carried on, and on any other similar construction, but with different conditions, he will know how to adapt his former data to suit the work in hand.

At times estimates on work in other lines may be desired, and resource may be profitably had to the contracting pages of "Engineering News," where detailed estimates of cost can be found in connection with the awards of contract. The "Letters to the Editor" in the same paper contain many interesting items on this subject, a late discussion having been on the cost of laying brick

pavements. In every engineering office estimates are continually being made, and in some places a great variety of work is handled. Surveys and estimates furnish the principal occupation in winter in many railroad offices.

Too much attention can not be given to the cost of construction, especially by the student engineer who is just entering his life of work. Promotion to higher positions and corresponding increase in responsibility and in salary will be made, not only for ability to design a beautiful structure or locate a railroad, but for the ability to make this an efficient design or location at the lowest possible cost.

THE HORSE POWER OF STEAM ENGINES.

E. C. OLIVER.

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In tests of steam engines the determination of the average performance by the use of the indicator is in some respects an approximation, in these tests it is the usual custom to take indicator diagrams from the cylinder or cylinders according to some predetermined system, these diagrams are then worked up and the results accepted as indicative of the true performance of the engine during the test.

In case the conditions are fairly constant during the test or if the changes are gradual, extending over several readings this method will give results accurate enough for any practical purpose. If, however, the changes in load are frequent and considerable in amount the diagrams may or may not represent the average conditions throughout the interval represented by the diagram and the results are not so trustworthy.

In any test the greater the number of observations taken in a given length of time, the more accurate will be the results, but in observations which concern the indicated horse power and with the apparatus now available for the purpose there is a limit to the number which it is possible to make. The time required in changing cards on the indicator and in adjusting and reading the revolution counter are some of the limiting conditions.

There has been some discussion as to the method of taking indicator diagrams which will give most nearly accurate results, especially with engines where a number of cylinders are involved and in tests under variable load. Some experimenters claim that to obtain most nearly average results that diagrams should be taken from both ends of all cylinders simultaneously at stated intervals; others would divide this interval into as many parts as twice the number of cylinders and take one diagram at each subdivision continuing with each cylinder in rotation until all cards are taken, so that the time between diagrams is comparatively short.

If a compound engine were under test the first experimenter would take one complete set of diagrams at say 10-minute intervals, while the second would divide this interval into four two and a half minute intervals, and at the first division take a diagram from the high pressure head end, at the second interval from the high pressure crank end and at the third from the low pressure head end, and at the fourth interval from the low

pressure crank end, then at the end of the next interval commence again with the high pressure head end.

Thus we have two methods of taking diagrams which we may distinguish as the method of simultaneous diagrams, and the method of diagrams in rotation.

What choice there is between these methods, should any exist, has probably not been determined experimentally; the

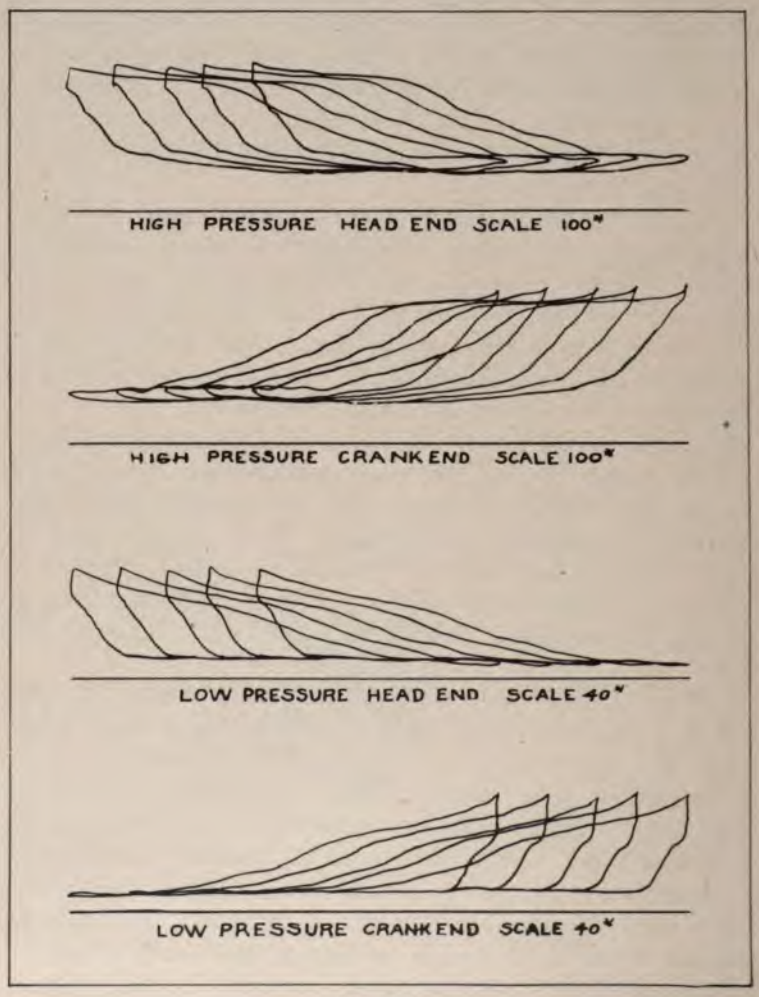

HIGH PRESSURE HEAD END SCALE 100"
HIGH PRESSURE CRANK END SCALE 100"
LOW PRESSURE HEAD END SCALE 40"
LOW PRESSURE CRANK END SCALE 40"

Figure 2

former method gives an accurate measurement of the power at the instant the diagrams were taken, while the second method does not give the accurate power at any definite time but is intended to detect and account for any change of load taking place between the more distant readings, the latter also has the advantage of requiring fewer observers.

While engaged in the Mechanical Engineering Department of

the University of Illinois the writer conducted a series of tests which were intended to point out, if possible, the effect on the average horse power of taking indicator diagrams at various intervals simultaneously and at various intervals in rotation.

The tests were run on a 10" and 16" by 12" tandem compound "Ideal" engine in the laboratory of the University, the engine being used to furnish light and power to the various shops and buildings on the campus.

The results were based on a test lasting seven hours and a half and extending over the noon hour when the load was almost entirely cut off. It was desired not to influence the results in any way by adjusting or changing the load but a few minutes before the end of the test the load became excessive and was partially relieved, the nature of the load is apparent in the graphical log (Fig. 1).

During the test indicator diagrams were taken from both ends of both cylinders simultaneously at intervals of two minutes, this was found by experiment to be about the minimum interval for obtaining diagrams that were satisfactory. Five diagrams were taken on a card as shown in the sample set (Fig. 2) by shortening the cord after each diagram was taken as is ordinarily done for this purpose.

The springs were calibrated and all the usual precautions taken to obtain diagrams and readings correctly.

The diagrams were all worked up and the results arranged in tabular form, the average of all readings being taken as the true average horse power throughout the whole test and the basis for comparison.

From this table of readings there were arranged other tables representing tests made under the systems previously referred to, the results showing the effect of a change in the time interval between readings as well as the effect of taking diagrams simultaneously or in rotation.

The results are embodied in three tables which follow:

TABLE I.

Time Interval Minutes	Duration of Test 9:12 a. m. until	Indicated by Test	Horse-Power Correct	Error
2	4:34	59.16	59.16	0
4	4:34	57.84	59.16	1.32
6	4:34	57.90	59.16	1.26
8	4:34	57.70	59.16	1.46
10	4:32	58.04	59.16	1.12
16	4:24	56.40	57.20	.80
24	4:40	58.73	59.40	.67
32	4:32	56.68	59.00	2.32

Table I is a summary of a set of tests in which the diagrams were taken from both ends of both cylinders simultaneously the time interval being variable. The first column indicates the interval between readings and the second the duration of the test; the third column contains the indicated horse power during the test as derived from diagrams taken at the intervals indicated in the first column. The fourth column contains the horse power averaged from all two minute diagrams taken between the times indicated in the second column. The fifth column gives the error of the various tests as compared with the values given as "correct," that is, the difference between the third and four columns.

TABLE II.

Time Interval Minutes	Duration of Test. 9:12 until	Indicated by Test	Horse-Power Correct	Error
8	4:34	59.18	59.16	+ .02
16	4:24	56.60	57.20	— .60
24	4:40	57.74	59.40	—1.66
32	4:32	57.90	59.00	—1.10

Table II is the same as Table I except that in this case the cards have been taken in rotation.

In Table III the two systems are compared and the errors of each system indicated in per cents.

TABLE III.

Time Interval Minutes	Indicated Horse-Power			Error in Per Cent.	
	Correct	Cards in Rotation	Simultaneous Cards	Cards in Rotation	Simultaneous Cards
8	59.16	59.18	57.70	0% low	2.4% low
16	57.20	56.60	56.40	1%	1.4%
24	59.40	57.74	58.73	2.8%	1.1%
32	59.00	57.90	56.68	1.8%	3.9%

Regarding the set of tests compared in Table I there is not sufficient uniformity of error due to a change of time interval to enable one to lay down any rule, in fact it has been mentioned before in this paper that the greater the number of readings in a given length of time the more accurate would be the results and yet this is disproved in these particular tests, by the results of the 24 minute readings which are less in error than any others. It is, however, noticeable that all the results are low and we might be justified in thinking that we would get results similarly low in another test under the same character of load.

The results of the tests in which diagrams were taken in rota-

tion, Table 2, are about the same as the previous set; the error does not follow any definite rule except that in all but one case the results are below the correct value and in the one case the results are practically identical.

The comparative error of the two systems of taking diagrams is indicated in Table 3 the results show that in a majority of cases the error is less with diagrams taken in rotation.

Whether any conclusions drawn from this set of tests would prove of general application is questionable, we may however state that the results of these tests show:

First: An increase in the time interval between readings did not introduce any error so long as there was a sufficient number of readings to cover the test fairly well.

Second: The results for tests with different time intervals and by taking diagrams either simultaneously or in rotation are in all cases below the correct value.

Third: The results of tests in which diagrams are taken in rotation are more nearly accurate than when diagrams are taken simultaneously.

Fourth: There is liable to be an error in tests of this character as great as three per cent where the readings are not in excess of twenty-five minutes apart.

DESIGN OF THE NEW POWER PLANT AND SYSTEM OF THE EVERETT RAILWAY AND ELECTRIC COMPANY.

EDWARD P. BURCH, E. E. AND M. E., '92.

Everett, Washington, is located on Puget Sound where the Great Northern Railway Line from St. Paul to Seattle first reaches salt or tide water. The city was platted in 1892. The population in 1903 is 20,000. The city is growing very rapidly, as are all the new northwest lumber and shipping towns of the Pacific coast.

The first electric railway and electric lighting plant in Everett was intalled in 1893 by Mr. Leo Daft. It had the following characteristics: Low pressure return tubular boilers, burning slabs for fuel; a high speed engine belted to a long countershaft which in turn was belted to several "Standard" 40 light arc machines; to three 45 K. W., 133 cycle alternators and to a 75 K. W., 500 volt railway generator. As the system grew two belted engines were added, also several small belted generators; and later a simple non-condensing belted Corliss engine. Finally, the railway plant was transferred to another building, a half mile distant, allowing room for temporary additions in the original plant.

In the course of time the electric lighting lines assumed a ragged appearance; the regulation of the overloaded lines became bad; the service was not reliable; the electric light meters were abandoned. The 40 pound girder rail on six miles of track began to warp and the joints to flatten as the fir ties rotted and sank in the clay; the service on one long grade which ran from 10 per cent to 13 per cent was abandoned; the trolley line became the talk of the newspapers who advocated new franchises for other interests. A deficit from the operation of the system was the natural result while depreciation on the property had been very rapid.

In 1901, the railway and lighting property was purchased by interests represented in the Everett Improvement Co., which company owned the town site, the city water system, the docks, etc. The purchase was made very largely because the old railway and lighting system was not being improved or extended or properly managed and thus it was hindering the growth of the city and the Improvement Co.'s land and other valuable interests.

The new president of the company, John T. McChesney, em-

NOTE.—An address delivered before the students in Power Plant Design at the University of Minnesota and published in the Street Railway Review, May 20, 1903. The accompanying illustrations are used through the courtesy of the Street Railway Review.

ployed the writer, consulting engineer of Minneapolis, to design a new plant, suitable for the rapidly growing city; also to supervise the reconstruction of and extensions to the old system. The designs and the equipments selected by the consulting engineer and placed in operation in April 1902, are given below:

The power site. This was chosen near salt water, (where the tide variation is 16 feet). The site is convenient for fuel and for fresh water supply. It is on the business side of the city and near the heaviest railway grades.

EXTERIOR VIEW OF THE POWER PLANT

The building. This is well shown by the accompanying photographs, plan and cross-sections. Its size is 103x88 and it is built with 24 inch brick outside walls. The cross-sectional design calls for two symmetrical halves separated by a 17 inch partition wall. The building may be extended in one direction for additional machinery without in any way destroying the symmetry or the economy of the original installation. The elevation of the boiler room floor was chosen largely with reference to the elevation of the railway tracks and the harbor water. One of the accom-

panying photographs shows the design of the exterior of the building.

The foundation. The building and machinery required that 1037 fir piles, 26 feet long and 20 inches in diameter be driven through the drift to firm footing. These piles were capped with three feet of concrete. The cement was Haccourt Portland. Beach gravel was used in place of crushed stone, as is common in government fortifications. The boiler foundations are of concrete. The engine foundations are of granite, (which is abundant) laid in large blocks.

The principal features carried out in the design of the Everett power plant are those which affect the economy of operation, i. e., the cost of fuel and labor per kilowatt hour output. These are:

Coal handling. Coal, a semi-lignite delivered for $1.75 per

FRONT OF BOILERS AND STOKERS

ton, comes in hopper bottom cars. It is weighed on track scales and is then dumped into a storage bin which has 400 tons capacity. The upper fourth, or the daily supply, runs through the chutes to the boiler furnaces. Thus the coal is not shoveled at any time.

Boilers. These consist of three Babcock and Wilcox vertical header type boilers. A fourth boiler will be installed this year. The steam pressure is 160 pounds; the heating surface 2649 square feet. These boilers are too well known to require description. The boiler and the piping arrangement shown, delivers dry steam, probably slightly superheated. under all conditions of operation.

The furnace. The Glasgow endless link grate stoker was

selected. The arch over the front of the furnace roasts or cokes the fresh fuel, as it enters gradually on the grate, under the arch, releasing the volatile gases which are burned in the combustion chamber above the bed of incandescent coke on the grates. There is complete combustion of the fuel before it is thrown as ash to the pit below. No smoke issues from the stack. The economy of steam production is remarkable high, due to the non-admission of cold air and to the entire combustion of the volatile matter. The temperature of the gases from the boilers is approximately 465° or 100° F. above the temperature of the steam.

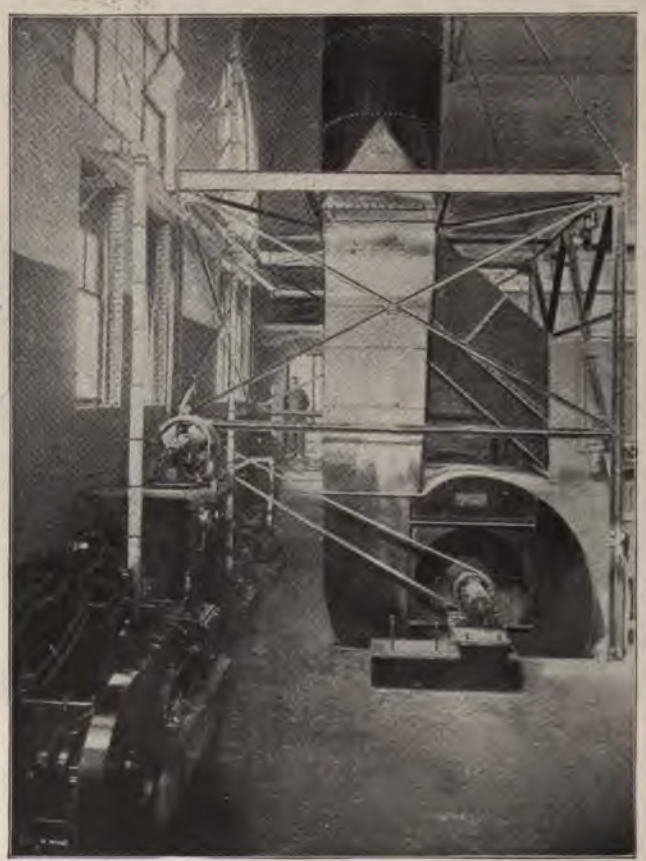
The boiler room is a very comfortable place to work in. Note the height to the roof. The furnace attendant has really a very clean and scientific job and efficient help is thus obtainable. Two

PIPING

boilers are used, and one is held in reserve. The two boilers are well loaded.

The draft. Mechanical draft is used. Two New York Blower Co.'s induced draft fans of the three quarter housing type are used to furnish the draft. They are 140 inches in diameter. The blast wheels are 84 inches in diameter and from 44 to 37 inches in width. One is engine driven, and one is motor driven, the latter held in reserve. About 15 H. P. is the maximum power required by the fans when furnishing a draft of 1¼ inches (of water) at the fan, which, owing to the mechanical resistance imposed by the economizer to the passage of the gases, is ½ inch at the furnace, during the maximum rate of combustion. The top of a 72 inch independently supported stack is 40 feet

above the grates. The speed of the fans is proportional to the load. It is governed by an automatic valve connected directly in the same header. This pressure regulator acts immediately when the steam pressure drops, speeding up the fan and increasing the draft, and vice versa. Induced draft is found to be flexible, always ample, easily controlled and independent of the wet weather prevailing on the Pacific coast. Thus lignite coal of cheapest volatile grades may be burned. This system provides for a rapid growth of the plant. The power required is small



INDUCED DRAFT INSTALLATION

and the exhaust from the engine is used to heat the feed water.

The arrangement shown of the smoke connections, the economizers, by-pass for economizers and for fans to use natural draft, and the arrangement of the fans themselves have been carefully studied out. The fan equipment itself requires little attention here.

Feed water heaters. The condenser uses ocean water. Therefore the feed water does not come from a hot well. Fresh water for the boilers is first sent to a Wainwright closed feed water

heater where its temperature is raised from 40° to 140° by the exhaust from the boiler feed pump, a dry vacuum pump, and a 15 H. P. induced draft fan engine. From the heater it is forced through a Green Fuel Economizer which raises the temperature to an average of 240°. This economizer plant is found specially valuable for the storage of heat. It increases the capacity of the boiler plant, the work in the boiler being decreased. The saving in fuel by the economizer is appreciable. The economizer heating surface is 2,688 square feet. It holds 10,700 pounds of water.

The generating units. There are simply two 500 K. W. Westinghouse electric generators, one for 550 volt D. C. railway work and one for 2,200 volt two phase lighting service, no reserve unit being installed. A second 500 K. W. lighting unit will be installed in 1904.

Each generator is direct connected to an 18" and 38" by 42" Allis-Chalmers Co. cross-compound engine. The speed is 100 revolutions per minute, making the piston speed 700 feet per minute. Two eccentrics are used for the steam and exhaust valves of each cylinder. A reheating receiver is placed between the cylinders. The fly wheel is 18 feet in diameter and weighs 45,000 pounds.

These engines on flour mill work in Minneapolis develop a horse power hour on 12.77 pounds of water. (Tests by Prof. Smith, formerly of the University, and recorded by Prof. Flather in the Year Book for 1901). At 92 per cent efficiency for the engine and 93 per cent for the generator this would be equivalent to 20 pounds of water per K. W. hour. At the time of purchase, April, 1901, small steam turbines were not a commercial success. The new Curtis turbine of April, 1903, it is said, will produce a K. W. hour on 19.3 pounds of water under the same conditions. The steam turbine has, however, great advantages in large units due to the possible use of high pressures and superheated steam.

In combined electrical lighting and electric railway service varying from 50 to 150 per cent of rated capacity (1-5th cut-off), there is required at the Everett power plant, from 26 to 28 pounds of water per kilowatt hour,—an exceptionally good record. Better results will be secured as the load factor of the engines improves.

The generators have a 50 per sent safe overload capacity for one hour,—following a full load run of 10 hours. The revolving field of two phase alternator is 12 feet in diameter and weighs 21,000 pounds. The armature of the railway generator weighs 29,000 younds.

Converter. A 300 K. W. rotary converter is used in a most interesting way. It simply converts from 550 volts direct cur-

rent to 380 volts two phase alternating current, which latter voltage is raised by two 150 K. W. static transformers to 2200 volts. The reverse operation is as easy and simply. By the use of this converter either engine when under-loaded may be shut down regularly for economy, and both the railway and the lighting service supplied by the other engine. The regulation of the converter is very satisfactory. There is an induction motor at one end of the shaft for starting from the A. C. side. On the other end of the extended shaft there is a small direct connected exciter which is used when converting from D. C. to A. C. to prevent any possible racing.

The use of this converter thus helps to furnish an electric generating system of minimum cost. It allows maximum engine economy since on the lighter loads one engine may be economically loaded, which is a most desirable feature in the design of a small power plant. The flexibility of the scheme in time of accident is also apparent.

In common operation one (either) engine runs midnight to 6 p. m.,and carries both the railway and the lighting service, after which both engines run during the remaining 6 hours of the day. The engines may be run in parallel if desired.

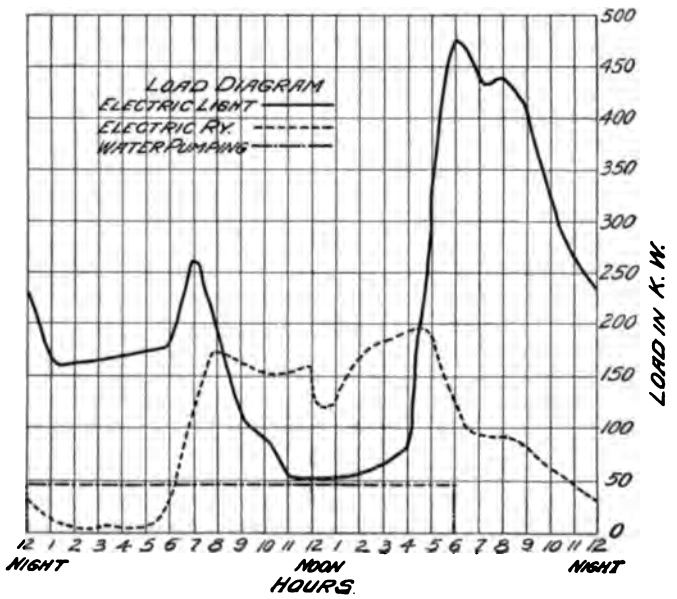
Switchboard. In the design of the switchboard the manufacturing company's standards were used in large measure. The panels are shown in one of the photographs. A Lincoln synchronizer is mounted over the board in plain sight of the engineman at the throttle. Indicating and integrating wattmeters are provided. The wiring is through lead covered cables. Ample space back of the board, good mechanical work and permanent construction are to be noted.

The condenser. A Worthington 20 inch elevated injector condenser is used. Salt sea water is used, being supplied by a motor driven 12" by 15" triplex pump located 1,500 feet from the power plant out on the company's docks. The speed of the pump, or the amount of injection water, is controlled in the power house by a Cutler-Hammer combination regulator which varies the resistence in the armature and field circuit. The power used by the motor when delivering 27,000 pounds of salt water per hour is but 4.77 kilowatts.

Pumping. City water pumping is provided for by a small triple expansion condensing Worthington pumping engine with a capacity of two million gallons per day. An old compound Worthington pump is held in reserve. Water is pumped up to a reservoir during the first 18 hours of the day, or when the lighting load is small. Thus extra men and additional boilers are not required. The economy of the whole plant, in pounds of coal per unit output was increased 8 per cent by the addition of

the pumping load. The water horse power of work by the pumps is reduced to K. W. hours. At 140 pounds pumping pressure, 1,000,000 gallons pumped per day are exactly equivalent to 1,000 K. W. hours output. The efficiency of the pumping engines on steady load is approximately equal to that of the railway and lighting service.

Auxiliaries. In importance, there is first a 20 ton Whiting traveling crane to reduce the labor item and to decrease the time required for inspection and repairs. There are several small motor driven accessories for the economizer, ash conveyor, etc., a Holly gravity return system of drainage to save all conden-



sation, a Sweet receiver, Finn traps, an automatic oiling system, etc.

The steam auxiliaries were recently tested by R. P. Stevens, superintendent, and D. P. Young, engineer. The steam was weighed, using a small special temporary condenser. It was found that the auxiliaries require the following pounds of steam per 24 hours: Holly system 2,300; boiler feed pump 2,360; stoker engine 975; dry vacuum or air pump 6,250; induced draft fan engine 2,050; total 13,935 pounds or from 6 to 7 per cent of the steam used by the engines. The heat units in the exhaust steam are entirely used to heat the feed water as stated.

Labor. The men work on eight hour shifts. Two men operated the plant on each shift, one in the engine room, one in boiler

room. There is one chief engineer over these six operators. The design of the plant allows a minimum of labor.

Metering. All water evaporated by the boilers is metered by cold water meters before it goes to the heater. Coal is weighed in cars only, except during tests. Recording wattmeters measure the total output. The engineer's daily reports show particularly the number of pounds of steam required per K. W. hour output; also the pounds of water evaporated per pound of coal burned. The results have been most satisfactory. The temperatures of feed water and of gases are recorded and studied.

Load diagrams. These are plotted from hourly readings. The railway and the lighting load peaks overlap during December and January. The pumping load is on from midnight to 5 or 6 p. m. and does not overlap the peak of the lighting load. These records of the plant are mailed to the consulting engineer daily. A common load diagram of Dec. 30, 1902, is reproduced herein. In summer, the water pumping and electric railway loads increase while the lighting loads decrease.

Economy. The economy of the power plant is best expressed by the number of pounds of water used per unit output. The results have shown the use of 26 pounds of steam per K. W. hour output during the past months. The steam pressure was 150 to 160 pounds; the temperature of the feed water 240° F.

The economy of production in power plants depends more on the load factor, i. e., the ratio of the average to the maximum load on the boilers and engines, than it does on any other variable item. This matter has received the greatest consideration in the design of the plant. The boilers have a fair load factor as shown, and by the use of the rotary converter to improve the engine factor an important advantage is gained.

The electric railway system at Everett consists at present of 13.0 miles of road. Extensions are now being planned to nearby cities and towns. The track is gravel ballasted, and a 60-pound tee American Society standard rail is used. The rail joints have a standard 8.4 pound angle bar and Brown plastic bonds.

A good patronage has been induced by new and modern Brill car equipments, good service, long runs for a nickel and a rapid schedule, which also saves in trainmen's wages. The gross earnings exceed $3.00 per capita per annum, which is high for a small city.

The electric lighting system for the city as remodeled consists of modern equipment. Single phase feeders are used, the product of their length by their amperes was made a constant. The regulation of lines is excellent. Eight commercial circuits

of No. 2 wire are used, and transformers located in the middle of each business block, the distribution being radial therefrom. Many Nernst lamps which have a high power factor were used in place of multiple A. C. arc lamps, by which the regulation of the transformers was greatly improved. The Hartford enclosed arc lighting system is used for municipal lighting. The gross earnings from electric lighting are over $3.00 per capita per annum.

The meter rates established for commercial lighting are, 16c per kilowatt hour for one hour's use of the maximum current on an average per day, 14c for two hours' average use of the maximum current per day, 12c, 11c, 10c, 9.5c, 9.0c, 8.5c, 8.0c, etc., to 5.0 cents for 3, 4, 5, 6, 7, 8, 9, etc., to 24 hours average use of the maximum current per day. These rates are proportional to the total cost of the electric current, i. e., operating expense, interest and a sinking fund. In order to determine just how many hours per day a consumer uses current on an average, one first divides the K. W. hours used during the month by 30. This gives the average K. W. hours used per day. Dividing this quotient by the maximum demand of the consumer in kilowatts and we have the average hours use of the maximum current per day. The maximum demand is measured, in large establishments, by reading the kilowatts from the consumer's recording wattmeter for one hour during the heaviest use of light. The maximum demand is seldom measured in residences, but is ordinarily assumed to be one-half of the installed capacity.

Electric power is furnished from the 550 volt grounded circuits without exception. A separate positive feeder was run for this service. It was considered a bad plan to install power service on lighting feeders. The matter of protection against fire and lightning was carefully considered in all power installations. Meter rates for electric power are approximately one-half of the meter rates for electric light.

General design. The plant and system as designed, for the entire city water, incandescent and arc lighting, electric railway and power service, show low first cost and high economy. "Specially" designed apparatus was not chosen. Sizes were thoroughly studied before purchase by first obtaining reliable data, using the knowledge of others freely, and getting correct technical facts as a basis. The commercial factors were recognized and engineering economy was not pushed to its full face value. The complication of many recent designs is avoided. Coal is not shoveled at any time and the stokers promote furnace efficiency. One man easily handles the battery of boilers. The piping is especially free from complications. The minimum amount of generating equipment used saves on investment, labor

and complication. Reliable service and maximum economy of the engines are guaranteed by the use of a rotary converter. (A magnetic clutch has been used by others to accomplish similar excellent results). Future needs will be supplied by the addition of similar units of the largest possible size consistent with economy.

The plant is considered reliable, economical and commercially consistent as a whole. The system is satisfactory to the stockholders because it is successful financially.

YEAR BOOK

OF

THE ENGINEERS' SOCIETY

1904

TABLE OF CONTENTS

DEAN F. S. JONES, ... Frontispiece

THESIS WORK OF 1903-4, ... 5

MANUFACTURE OF HIGH EXPLOSIVES—*R. S. King*, ... 17

EFFECT OF CONCENTRATED LOADING ON CONCRETE BLOCKS—*P. S. Smith*, 25

EFFECT OF FREEZING ON CONCRETE—*P. I. Gunstad*, . . . 29

ELECTROSTATIC CAPACITY OF WIRES—*G. D. Shepardson*, . . 32

SOLUTION OF PROBLEMS IN SPIRAL GEARING—*E. C. Oliver*, . . 43

UNIVERSITY HEALTH COMMITTEE AND ITS WORK—*F. H. Bass*, . 49

EXPERIMENTAL ALTERNATING CURRENT SERIES MOTOR—*J. C. Vincent*, 52

SOME NOTES ON ROPE DRIVING—*J. J. Flather*, ... 63

CONSTITUTION OF ENGINEERS' SOCIETY, ... 82

ANNOUNCEMENT

The YEAR BOOK is a scientific publication issued by the Engineers' Society, of the College of Engineering and the Mechanic Arts, University of Minnesota.

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YEAR BOOK

OF

THE ENGINEERS' SOCIETY

UNIVERSITY OF MINNESOTA

MAY, 1904 VOL. 12

THESIS WORK OF 1903-4.

It has been thought that a review of thesis work done at this university would be of general interest. To get an accurate description each set of investigators was asked to hand in a synopsis of their work which should state briefly the objects and methods. These sketches will be found below.

CIVIL DEPARTMENT

DESIGN OF OVERHEAD RAILWAY CROSSING

N. H. BOGUE AND FRANK O. FERNALD.

The elimination of grade crossings along the routes of our railroads and especially within the limits of our large cities has became a question of serious consideration, and its importance is recognized alike by both the railways and the public.

In the east this is no longer a question but a settled fact, and railway corporations are far-sighted enough to recognize the economy in the relief from too numerous and costly accidents and the maintenance of the gates and flagmen of grade crossings, to say nothing of the increased high speed and efficiency of the train service within corporate limits.

A striking example of the question is seen in the numerous and elaborate improvements recently made in Chicago. In Minneapolis the conditions are fast becoming such that the need of eliminating grade crossings within its limits, is imperative, and for one of the most important of these, the intersection of University Ave., Oak Street and the Nor. Pac. Ry., it is the purpose of this thesis to show ways and means of economically meeting the conditions of the problem.

Oak street carries a street car line averaging a car every seven minutes. University Ave. is a through highway between Minneapolis and St Paul and a great deal of hauling is done over this avenue between the two cities. The railroad is double track and is used for high speed passenger and freight service by several companies—fifty or sixty trains passing the crossing daily.

The solution proposed is to lower the streets fourteen feet and raise the track two and one half feet (all that the governing conditions, grades, etc., will allow).

The design of the steel work and masonry of the railway bridge is the main feature of the thesis.

Conditions are such that a skew bridge is necessary. This consists of one 20′ sidewalk span, a 42′ skew span on one side and a 95′ skew span on the other, another 95′ skew span and a 40′ skew sidewalk span. Plate girders will be used throughout. Equal spans are duplicates.

An alternative design is submitted, consisting of a combination plate girder and pony truss bridge. In this design the sidewalk spans are as above, but for the 95′ and 42′ plate girders are substituted riveted trusses 10′ deep.

The floor, which is common to both designs, consists of solid rectangular troughs with concrete filler covered with ballast. This type of floor reduces the thickness necessary, thus aiding the clearance and insures those passing underneath immunity from dripping and like inconveniences.

Comparison is made with other types of floors showing the advantages of the form used.

General drawings are submitted of both designs and all appurtenances, including shoes, pin ended supporting columns, plans and specifications for concrete foundations, abutments and retaining walls. A comparison of the advantages of each design, including cost, together with an estimate of the total cost of the improvement, completes the thesis.

CONCRETE-STEEL.

F. E. DOWNING AND J. C. HOLLAND.

Two series of tests in concrete-steel are being made. In one series the adhesive coefficient of concrete and steel is sought for, and in the other the formulae for the design of concrete-steel beams are to be tested experimentally. In Prof. Burr's formula the adhesive coefficient is one of the factors, so that these two series are complementary to each other.

(a.) To get the adhesive coefficient the authors have made

eighteen blocks of concrete 9″ x 12″ and varying from 12″ to 20″ in length. From one end of each block project two steel rods, spaced six inches apart. Midway between these two and in the same plane is a test piece imbedded in the block and projecting from the opposite end from which the two rods project. (See Fig. 1.)

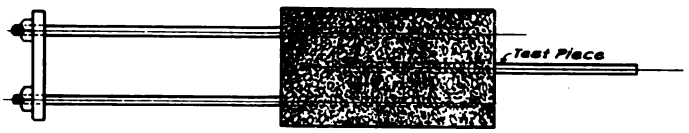


FIG. 1.—BLOCK FOR ADHESION TEST.

The rods are commercial steel, round and square, and of three sizes each, viz. ⅝″, ¾″ and 1″. Knowing the depth the test piece is imbedded and knowing the number of pounds necessary to pull the test piece out, it will be a very simple process to find the adhesion per square inch of surface of metal exposed to the concrete.

(b.) Six beams have been made of 1 : 2 : 4 concrete that are 8″ wide, 12″ deep and 10′ long, with steel of different shapes imbedded on the lower side 1½″ from the bottom. (See Fig. 2.) Two concentrated loads will be placed upon these beams 26″ apart, and the beams tested to destruction. Passing through each beam are two ⅛″ gas pipes, threaded on each end and 18″ apart. These will be used to fasten extensometers to in order to get the amount of compression on the upper side and the amount of extension on the lower side. By plotting the extensions and corresponding compressions the positions of the neutral axis under varying loads can be found and this once determined the stresses in every part of the beam may be determined.

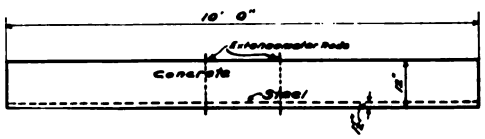


FIG. 2.—BEAM FOR TRANSVERSE TEST.

Furthermore, test pieces of the concrete used in the beams have been made so that the moduli of elasticity in tension and compression of the concrete used can be used in the formula for the design of the concrete steel beams tested.

WATER AND SEWERAGE SYSTEM.

N. B. NELSON AND PAUL ROTHI.

Nelson and Rothi took for their thesis the design of a water and sewerage system for Excelsior, Minnesota, a residential city and summer resort. As the town is situated near Minneapolis, it gave them a good opportunity to collect very complete data. A profile survey of the town was made; elevations of nearby hills for water storage were found, locations of the various parts of the system were made and depths of existing wells in the vicinity and their capacities were obtained.

The design was made on the basis of a future population of about 3000. Daily consumption was taken as 60 gallons per capita; fire capacity, 4-200-gallon per minute streams.

A well supply was considered, but the depth, number of wells and uncertainty of flow makes it necessary to have Lake Minnetonka as the source of supply. There is no danger of pollution at the present time, and if purification ever becomes necessary, the grounds near the pumping station make an ideal location for a filtration bed at a very small cost.

An 80,000 gallon storage tank upon a steel tower 100 feet high, located about 1000 feet from the center of the town, gives an average static pressure of 70 pounds per square inch. Among the other features in this design are an intake and the laying of about 300 feet of submerged pipe.

The power for lifting the water is furnished by 2 gasoline engines, directly connected to 2 triplex pumps, combined capacity 800 gallons per minute.

The separate system of sewerage was thought best, as the topography of the town is such that storm water can be quickly diverted into the several lakes. As Lake Minnetonka is the only possible place for sewage disposal, it becomes necessary to purify the sewage on account of the use of the water for public purposes and also to accord with the state law. This necessitated low grades to prevent the raising of sewerage by pumps. The average velocity, in the main sewer being rather small (about 1.4 feet per second), some method of cleansing the sewer is required. This in done by flush tanks.

The sewerage purification plant consists of a septic tank and an intermittent filter, with a capacity of 180,000 gallons per 24 hours.

The two systems were designed to be practical and within the financial reach of the town.

MECHANICAL DEPARTMENT.

THE STEAM CONSUMPTION OF PUMPS.

R. W. OTTO and R. E. STANTON.

The object of this thesis is to determine the steam consumption per horse power delivered, and the slip at various rates of flow.

These tests were made on various sized pumps, varying from small boiler feed pumps of a capacity of fifty gallons per minute, to deep well and service pumps of a capacity of 500 to 1,000 gallons per minute.

The method of making the tests was as follows: For small pumps the water was run into a large tank and from here pumped into weighing tanks against heads of 60, 80, 100, and 120 pounds, respectively. The steam consumed was determined by leading the exhaust steam through a condenser coil, of suitable capacity, and weighing at the end of the run. A series of six runs was made, at rates varying from .445 cubic feet per minute to ten cubic feet per minute for each head.

For the larger pumps, consisting of deep well and service pumps, the water delivered was determined by passing it over a weir. The steam consumption was determined as in the above case. The rates of flow varying from five cubic feet per minute to 100 cubic feet per minute.

The H. P. delivered was determined in each case by the above known weights and heads. Also, knowing the steam consumption per hour and the D. H. P., the steam consumption per D. H. P. per hour was easily computed.

The following results were taken from an average boiler feed pump, size $6'' \times 4'' \times 5''$.

	Heads	RUNS					
		1	2	3	4	5	6
Time	60	30	30	30	30	30	22
Cubic feet per minute		.703	1 89	3.104	4 302	5 86	6.031
Piston speed in feet		25 5	40	57	72	101	118
D. H. P		.188	.504	.825	1.15	1.599	1.661
Steam per D. H. P. per hr.		653	306	252	204	162	178
% Slip		67	43	34	28	30	37.5
Time	80	30	30	30	30	30	20
Cubic feet per minute		.445	1 165	2.428	3.434	5.014	5.757
Piston speed in feet		18.5	27.4	44	58 4	81	95.5
D. H. P		.158	.415	.865	1.22	1.79	2.04
Steam per D. H. P. per hr.		593 5	346 5	231.8	192.1	149.1	124.9
% Slip		71	48	33	28 5	24 5	27

	Heads	RUNS					
		1	2	3	4	5	6
Time	100	30	30	30	30	20	20
Cubic feet per minute		.537	1.6	2.469	3.326	4.826	5.744
Piston speed in feet		21.5	34.7	47	61.2	87	104
D. H. P.		.236	.709	1.091	1.478	2.13	2.55
Steam per D. H. P. per hr.		513.6	219.2	165.4	155	131.8	126.8
% Slip		.....	.....	.....	.....	.....	.....
Time	120	30	30	20	20	22	.....
Cubic feet per minute		.476	1.559	1.966	3.117	4.03	.....
Piston speed in feet		22 5	35.4	47	55.9	73.5	.....
D. H. P.		.251	.829	1.04	1.647	2.144	.....
Steam per D. H. P. per hr.		656	216	209.	153.2	145.1	.....
% Slip		74	46	50	35.8	33	.....

CALIBRATION AND APPLICATION OF THE OLIVER AUTOMATIC RECORDING MACHINE.

G. N. DAVIS AND S. R. FAGER.

The Oliver Recording Machine is designed with the object in view of recording on a single sheet of paper the momentary changes of conditions throughout a test, thus producing a sort of graphical log to be used as a basis of calculation for the final results.

FIG. 1.—OLIVER AUTOMATIC RECORDING MACHINE.

Fig. 1 shows the machine, and Fig. 2 shows it as connected to an Otto Gas Engine. In the upper left hand corner, can be seen the flexible shaft which connects to the shaft of the

engine and drives the machine. On the right the paper is seen as it leaves the roll and passes under the recording pens. The gears on the left are for driving the paper through the machine. The pen which records the speed is actuated by a disc governor, which tends to assume a position at right angles to the rotating shaft. The disc in assuming different angles in consequence of variations of speed, operates a cam which, in turn, acts on a system of rods and levers, which determine the relative position of the pen to the base line.

FIG. 2.—RECORDING A GAS ENGINE TEST.

The developed H. P. was obtained by means of a Prony Brake. The load on the end of the brake arm was applied to an oil piston, which transmitted the pressure through a ¼" pipe to a Crosby Indicator on top of the machine, as shown in Figs. 1 and 2.

The four pens to the right in Fig. 1 are connected by a system of levers to the armatures of electro-magnets, so that the closing of a circuit by any means will cause one of these pens to shift, thus indicating by a jog in the line some movement, a record of which is desired. The other pens are held in runners which slide on a square bar.

This machine was designed by E. C. Oliver of the Mechanical Department of the University, and was constructed in the University Machine Shop.

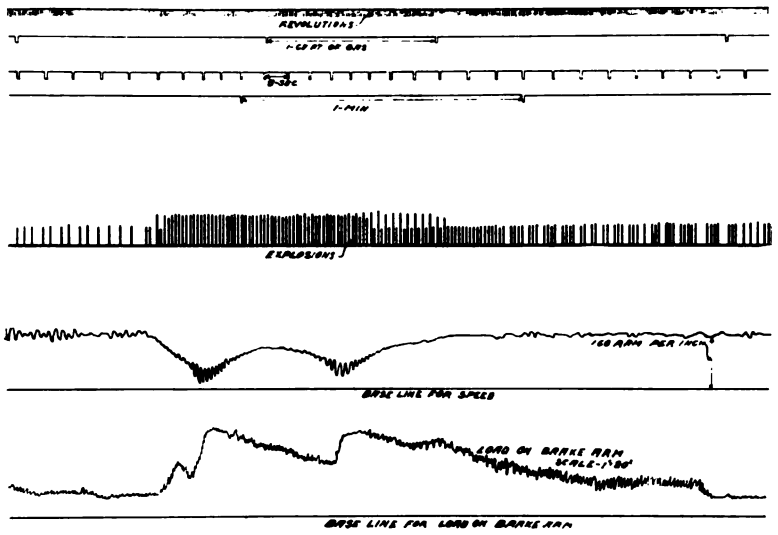


FIG. 3.—RECORD FROM TEST OF OTTO GAS ENGINE.

The machine has been calibrated and a new cam designed, which gives ordinates on the paper proportional to the speed. After the machine was calibrated, and all parts adjusted, it was connected to an Otto Gas engine, as shown in Fig. 2, and a record was obtained as shown in Fig. 3.

ELECTRICAL DEPARTMENT.

DESIGN OF A CONSTANT TORQUE SINGLE PHASE MOTOR

FRED A. OTTO AND JOHN WICKS.

In designing a constant torque single phase motor, the problems to be met and overcome are: to design a motor that shall be self-starting on single phase alternating current, and that shall give a practically constant torque over a wide range of speed, varying from standstill to near synchronism, the speed to be varied at the will of the operator.

From tests made on a single phase motor, having an armature and commutator wound as for direct current, and run as a repulsion motor pure and simple, it was found that a high starting torque was obtained; but as the speed increased the torque fell off rapidly, until the speed of the motor was near synchronism, when the torque was practically zero.

On the other hand, by taking off the brushes and running the same motor as an induction motor with a three legged resistance

in its rotor circuit, it was found that the torque at starting was zero, and gradually rose to a maximum shortly before the speed of the motor reached synchronism. This is exactly the opposite of the behavior of the repulsion motor.

If then a motor is designed combining the features of a repulsion motor, and a single phase induction motor, as described, the net torque at any speed will be approximately the sum of the torques due to the repulsion motor and to the single phase induction motor respectively, and will vary between comparatively small limits.

In order to obtain data and information upon which to base calculations and verify formulae, a series of tests were made of a single phase Wagner Induction Motor. This motor starts as a repulsion motor and when up to speed, automatically short circuits the armature and throws the brushes off the commutator, after which it runs as a single phase induction motor. Tests were made running as a repulsion motor and then as a single phase induction motor. Three slip rings were then secured to the shaft and connected to the armature winding at points 120° apart. These slip-rings were connected to each other through brushes and a three legged external resistance, which could be varied through desired limits. When starting, this resistance is inserted in full in the rotor circuit, and the current induced in the armature flows by way of the short circuited brushes. The motor then starts as a repulsion motor. As the speed increases the resistance in the motor circuit is gradually cut out, thereby allowing a part of the current induced in the armature to flow through the resistance, and the motor begins to act as a single phase induction motor.

Tests were made using this arrangement and a torque approximately constant was obtained. A single phase motor as described was then designed for constant torque at all speeds. The brushes were short circuited and a three-legged resistance inserted in the rotor circuit. By this means the motor was made self-starting, the speed being varied by means of the resistance in the rotor circuit, while the torque varied to a comparatively small extent.

POWER REQUIRED TO OPERATE ELECTRICALLY DRIVEN MACHINES.

JOHN HOWATT AND V. E. GOODWIN.

In obtaining data for this thesis a series of tests covering a period of two weeks, were made at the shops of the Chicago and Great Western Railway, at Oelwein, Iowa. The machines in these shops are group and individually driven by 220 volt direct

current motors. The current for these motors is furnished by a power house having a combined output of 700 K. W.

The tests were made in view of obtaining the average power generated and its cost, the distribution of the same to the several shops, the power required to operate the different groups and individual machines on various classes of work and the net time of operation of each machine, special attention being given to machines used in handling and transporting stock and engine materials about the shops. The latter consist of a 120,000 pound hoisting crane, a 30,000 pound traveling crane, a transfer table, a derrick, a coal hoist and a deep well pump. To obtain good average results, a wattmeter was placed in each circuit for a period of from three to five days. The fluctuations in load in the different circuits were obtained from ammeter and voltmeter readings. Electric clocks were placed on a number of important machines in view of obtaining their net time of operation. The power required to overcome the friction of shafting and bearings of machines was obtained for each shop. A complete test was also made of a 125 H. P., compound, two stage air compressor.

It is hoped that the results obtained for this thesis will enable the Chicago and Great Western Railway Company to charge to each shop and to each machine the power which it actually consumes in doing a certain kind and quantity of work.

From the above data and other available material it is expected to make plans of lay-out of machines and motors for the Jackson Street Shops of the Great Northern Railway, at St. Paul, Minn. The power is to be delivered over a 2,200 volt, three phase transmission line from the company's new power house at Dale Street, and distributed at 440 volts to three phase induction motors. The problem above presented consists of the design of the transmission line, the transformer station and the proper grouping of the machines for advantageous work and minimum amount of power.

STREET LIGHTING WITH 32 AND 50 C. P. INCANDESCENT LAMPS.

R. B. TAPLIN.

The question of using incandescent lamps for municipal lighting is one which is increasing in prominence as the manufacturers of lamps succeed in increasing the efficiency and useful life of high candle power lamps.

Recognizing this fact, it has been the object of the present investigation to determine the average life of a thirty-two and a fifty candle power lamp at pressures of one hundred and ten and

two hundred and twenty volts, and to estimate the utility of such lamps for illuminating purposes when compared with the common methods of street lighting. A series of tests for candle power and efficiency at various periods during the life of the lamps was made, and curves showing the performance of the lamps were obtained from these tests. Tests of illumination were made under conditions as nearly identical with those of actual service as it was possible to obtain and the results compared with those obtained from tests of other illuminants.

It is thought that such an investigation will show that incandescent lamps of such candle power as to compare favorably with the mantle burners, etc., now used, may be economically employed in a great many instances in street lighting.

MEASUREMENT OF TELEPHONIC CURRENTS

L. C. TOMLINSON AND H. G. MORTON.

Telephonic currents are known to be very small, but up to the present time no systematic investigation has ever been carried on to determine their exact value. The main difficulty has been the absence of an instrument sensitive enough to show the presence of such currents. Such an instrument has been designed and constructed in the laboratory, and is now in use. It consists primarily of three coils, two of them of heavy construction and so made as to leave a hollow spherical space between the coils when placed end to end. The third coil is composed of very fine wire, No. 36, and is hung by means of a fine steel suspension so as to swing in the space between the large coils. A small mirror attached to the suspension shows the position of the coil. Readings are taken by means of a telescope and scale placed at a distance of 2.75 meters from the mirror. The instrument will show a sensible deflection with a current of 0.00001 amp. Tests are to be made with this instrument on transmitters and repeating coils of various types in various combinations, and it is expected that considerable information will be obtained in regard to the action of such apparatus. Tests will be made on long distance lines and the action of repeating coils of various types and makes will be thoroughly studied.

DESIGN OF A SINGLE PHASE MOTOR FOR TRACTION WORK.

B. BOUMAN AND F. C. HELMS.

The direct current series motor, as used on street railways today, has reached a high degree of perfection and the system is

an admirable one for city work. But, when we come to long distance interurban lines which are to compete with steam roads, we have to look for alternating currents and their attendant advantages in transmission at high voltages.

The outline of the work as pursued is as follows:

First, the few articles available in American papers and a few of those in German periodicals were thoroughly reviewed. The thesis of Mr. J. C. Vincent, '03, which was on this subject, was also studied and complete prony brake tests made on the motor designed and constructed by him, the motor being run on direct current and alternating current, the latter being of 26 and 68 cycles.

From these tests a good idea was obtained of the principle characteristics of the motor. Other tests were made to ascertain certain technical points to aid in the design of a new motor. From the information obtained it is hoped to design a motor which will be free from sparking at the commutator.

It is only a matter of four or five years before speeds of seventy-five to one-hundred miles an hour will be used on electric roads operating between large business centers.

EFFECTS OF DIFFERENT SHAPES OF E. M. F. CURVES ON COMMERCIAL APPARATUS.

GEO. N. CRABBE AND EDWARD J. CHENEY.

The object is to determine the most efficient wave shape for each kind of commercial apparatus.

A General Electric 7½ K. W. double current generator is used to supply the current. As manufactured the machine gives a sine wave form, and special poles have been designed and manufactured which will give peaked and flat topped wave forms.

Tests with each of these wave shapes are being made on transformers, synchronous and induction motors, and incandescent and arc lamps. Sparking distance and strength of dielectrics will also be found for each wave.

The machine is being tested with each set of poles for efficiency as a generator of both alternating and direct currents, as a motor run from either side and as a converter run both ways.

In connection with this investigation considerable work has been done with the Duddell Oscillograph, recently secured by the University. This instrument has been set up and adjusted, and suitable apparatus designed and constructed for use with it. The oscillograph is used for obtaining wave forms of current and E. M. F. in each test.

THE MANUFACTURE OF SOME HIGH EXPLOSIVES.

R. S. KING,

Instructor in Mechanical Engineering, University of Minnesota.

In the manufacture of high explosives the first question that presents itself to the engineer is, "Can so and so be done without causing some one's injury or death?" An engineer who is not careful and cool-headed has no place in the manufacture of explosives. This article will deal mostly with the processes of manufacture of nitroglycerine, gun cotton, dynamite, gelatin and a black powder known as Judson's or Contractor's powder.

FIG. 1.—INTERIOR OF NITRATING HOUSE.

The buildings composing a plant for the manufacture of high explosives are generally small and entirely isolated from each other. Those buildings directly connected in the manufacture and liable to destruction by explosion should not be nearer to each other than 400 feet. Where blasting or rifle powder is manufactured the buildings are surrounded by wooden barricades. In the case of higher explosives, the buildings are either built into the side of a hill, as shown in Fig. 6, or earthen barricades are thrown up. This method of protection prevents the scattering of fire and damage to other buildings when explosion does occur. In the manufacture of high explosives it is necessary that the buildings

should be heated, as the product becomes dangerous when in a frozen state. This question of heat, not only makes the cost of manufacturing high in winter time, but gives the engineer all the practice he wants in keeping up a long pipe line where condensation, expansion joints, etc., all play their part in causing trouble.

The problem of transportation of the material from one building to the other is solved by means of the industrial railway, push trucks on wooden runways and pipe lines. The industrial railway is usually of a narrow gauge and light rail. The cars being pulled by mules or horses. The track must be kept in good condition and great care must be taken that the men are careful in the handling of explosives. Push trucks on wooden runways only are used in conveying the nitroglycerine from the store houses to the mixing houses. Pipe lines are used to convey the sweet glycerine, acids, water, steam and compressed air to the buildings where they are needed.

FIG. 2.—INTERIOR OF WASH HOUSE.

The power plant contains boilers, engines, generators, pumps and air compressors. This equipment is in duplicate, one set being held in reserve so that upon a moment's notice it can be started up. This is necessary, as some of the processes can not be stopped when once started without great danger or loss of materials.

Nitroglycerine is a product of sweet glycerine and nitric acid. In order to carry on the process safely the nitric acid is mixed with sulphuric acid. These acids are concentrated and mixed in

the proportion of about one part nitric to two parts sulphuric. The glycerine and mixed acids are stored some distance from the nitrating house and the charges, which have been weighed, are forced by means of compressed air through pipe lines to the nitrating house. Two processes of nitrating have been successfully used. One is known as the compressed air agitator, and the other as the mechanical agitator.

Figure 1 shows the interior of an air nitrating plant. In the upper right hand corner stands the nitrating machine. This consists essentially of a lead tank with a number of lead coils running through it so that water can be used in keeping the charge cool. A perforated lead coil is laid on the bottom of the tank and one end connected to the air supply. Into this lead tank or nitrator is

FIG. 3.—HAND MIXING DYNAMITE.

introduced the charge of mixed acid; the air is then turned on to agitate the charge. Sweet glycerine is then fed in a number of fine streams into the top of the nitrator. A thermometer is kept in the charge. The temperature running from 75° F. to 85° F. being the safest. After the glycerine is nitrated the charge is run down into the separators shown in the foreground of the picture. These separators are provided with cooling coils. The nitroglycerine soon separates and comes to the top. After standing for an hour and a half the spent acid is drawn off and conveyed by lead pipe lines to what is known as the second separator, where it stands from four to six days to allow the remainder of the nitroglycerine to separate. The nitroglycerine in the first separators is then drawn off into a tank containing water which is being agitated by compressed air. From here it is conveyed through a lead

pipe line to the wash house. Beneath the nitrator and separators is a large tank filled with water. This is known as the drowning tank. Sometimes the nitroglycerine ignites during its manufacture. When this happens the operator shuts off the supply of sweet glycerine and then, if the fire does not die out, he opens a faucet at the bottom of the nitrator and runs the charge into this drowning tank. Having opened this faucet he leaves the building to seek a place of safety, but on the way out of the door he pulls a lever which blows a whistle to warn his fellow workmen that his mill is in a dangerous condition. Should the charge be successfully

FIG. 4.—HAND MIXING DYNAMITE.

drowned, the nitroglycerine settles to the bottom and is drawn off. In the mechanical nitrator the charge is agitated by paddles instead of air.

The interior of the wash-house is shown in figure 2. To the right is shown the lead wash tanks. Into these tanks is run the charge of nitroglycerine mixed with water which has been conveyed from the nitrator by a pipe line. Here the nitroglycerine is washed in two or three changes of water and once in a weak alkali bath, to insure the removal of every trace of acid. From the upper faucets is drawn the sour water which is conveyed by a trough to a pipe line which leads to a small building. In this building are a number of tanks fitted with baffle plates, which prevent the nitroglycerine running out with the waste water. The washed nitroglycerine is drawn from the lower faucet into a trough. This trough leads to a push car which conveys the nitroglycerine to the tank house where it is stored until used.

The ordinary grades of dynamite are made by absorbing nitroglycerine in a material made up of wood pulp, nitrate of soda, flour and sometimes a small amount of coloring matter. Dynamite may be mixed in two ways: by hand or machine. Figures 3 and 4 show the method of hand mixing. Here the absorbing material is put into a wooden tray and is spread out, the nitroglycerine is then poured over it and the whole thoroughly mixed by raking, as shown in Fig. 3. The mixture is then shovelled to one end and a screen placed above the tray and the mixture run through this to break up any clods or lumps. Fig. 4 shows this part of the process. 200 pounds can be mixed at a time by this method and the operation requires about thirty minutes. Figure 5 shows a mixing machine. Here the absorbent is placed in a circular trough and the nitroglycerine poured over it. The machine then revolves and

FIG. 5.—MACHINE DYNAMITE MIXER.

the wheels, by their weight press the charge down, and a plow follows which turns it over and breaks it up. These machines mix from 400 to 500 pounds at a time and require about twenty minutes to mix a charge. Great care is needed in mixing as this is one of the most dangerous parts of the process.

From the mixing house the dynamite is conveyed by cars to the packing houses. Fig. 6 shows how the packing houses are built into the side of a hill. Fig. 7 shows the interior of one of these houses. To the left in the picture is shown the empty paper shells. To the right is shown a packing hod. The dynamite is put in this hod and is then fed into a funnel which fits a hole in the bench in front of the hod. The empty paper shell is then put under the funnel and rests on the block which is fastened to one leg of the bench. The dynamite is then packed into the shell by means of the packing sticks shown on the wall to the right. From the packing house the cartridges go to the dip house where they are dipped into paraffine to make them

waterproof. From here they are taken to the case house where they are packed into 25 and 50 pound cases. The dynamite is then ready for the market.

Blasting gelatin, or gelatin dynamite as it is often called, is made by absorbing nitroglycerine in guncotton, wood pulp and nitrate of soda. The gun cotton is made by nitrating cotton waste in a mixture of nitric and sulphuric acids. After being nitrated the gun cotton or nitrocellulose is thoroughly washed both in clean water and in a weak alkali wash. The cotton is then put in a beater, similar to the pulp beaters in a paper mill, and beaten to a fine powder. After being thoroughly dried it is ready to use in making gelatin dynamite. Fig. 8 shows a gelatin mixing machine of 400 pounds capacity. The kettle is surrounded by a water jacket which keeps the gel-

FIG. 6.—EXTERIOR OF PACKING HOUSES.

atin warm while mixing. The paddles shown in the figure are lowered during the operation of mixing. After the gelatin is mixed it is soft and plastic just like putty. The packing is done by machinery.

Contractors' or Judson powder is made by mixing nitrate of soda, sulphur and charcoal together and heating in a steam jacketed cylinder until it fuses and makes the material form into grains similar to but somewhat coarser than rifle powder. This material is then mixed with about 5% of nitroglycerine and packed in paper sacks and cased.

Very erroneous ideas are entertained as to the danger of handling, storing and transporting high explosives. Dynamite is safer in every respect than common powder. It will burn

without explosion if not confined. It burns with a light blue flame and in several instances many thousands of pounds have been consumed without any explosion whatever. It will withstand any shock incident to handling or transportation. Some experiments were made with Aetna dynamite by hurling cartridges of dynamite from the Louisville bridge to the bare rocks below, a distance of over 100 feet, and they withstood this severe test without exploding. Dynamite requires a strong blasting cap.

FIG. 7.—INTERIOR OF DYNAMITE PACKING HOUSE.

The following table will give a fair idea of the use of the different grades

20% N. G. 25% N. G. 27% N. G.	For clay, shelly rock, frozen earth and light work; and in quarries where rock is to be split but not shattered.
30% N. G. 33% N. G. 35% N. G. 40% N. G.	For moderately hard rock, copper, lead and other ores, stumps and ice.
45% N. G. 50% N. G.	For hard rock, ores and iron.
60% N. G. 75% N. G.	For extremely hard rock, ores, breaking iron and steel and submarine work.

Gelatin dynamite is more difficult to explode than dynamite, and extra strong detonating caps should be used. It is practically free from fumes and hence is well adapted for work in tunnels, shafts, mines and other places where there is poor ventilation. It is used in submarine work.

Contractors' or Judson powder should be exploded by a

small cartridge of dynamite. This powder is used largely for blasting seamy rock, tough clay, hard pan and in lime stone quarries.

The methods in use for exploding dynamite are by safety fuse, inserted in an explosive cap made expressly for the purpose, and fired as in ordinary blasting; or by means of electricity.

FIG. 8.—GELATIN MIXING MACHINE.

A few words might be said in regard to the safe handling of nitroglycerine. If nitroglycerine be dissolved in alcohol a non-explosive compound is formed, and hence can be conveyed any distance with safety. In order to reclaim the nitroglycerine the compound is poured into water and the nitroglycerine separates itself and settles to the bottom and can be drawn off. Should nitroglycerine be spilled it can be washed up by alcohol or better still by a strong solution of alkali which will destroy it entirely. Nitroglycerine should not be given a sudden jar or shock. Should a bucket full be dropped from a height the jar would cause it to explode; but if it was poured out like water the chances of an explosion would be very small.

ABSTRACT OF THESIS ON

EFFECT OF CONCENTRATED LOADING ON CONCRETE BLOCKS.

P. S. SMITH, C.E. '03.

(Abstract made by J. C. Holland, '04.)

The object of this experimental work is to obtain some further data along the line of *resistance to concentrated loading* on concrete material and, if possible, to point out some general law governing the action of concrete under these conditions.

Since the object of this work is especially to observe the effect upon internal elements from those external to them, it seemed advisable to use a constant compression area and constant depth with a varying exterior, to get direct observations on the same object under different conditions, and to simplify results by preventing the confusion of variable elements in the limited number of experiments. The experiments were limited to two materials—a common concrete mixture and its mortar. The sizes made were: (1) 12'' x 12'' x 6''; (2) 10'' x 10'' x 6''; (3) 8'' x 8'' x 6''; (4) 5'' x 5'' x 6''.

The materials used were: (1) Saylor cement, a medium Portland; (2) Bryn Mawr unscreened sand; and (3) Stone thru the kindness of Langdon Stone Co., of the size limited by ½" and 1¼" rings and free from dust.

The proportions used were: 1 part cement, 3 parts sand and 5 parts broken stone, all by volume, this being selected as the most common mixture for concrete. The mortar blocks were made of 1 part cement and 3 parts sand, by volume. The percentage of water used was the same in both concrete and mortar blocks. From 15% to 17% by weight of mortar was used. This percentage gave what is commonly called a "wet concrete" which quakes slightly on tamping.

The blocks made were put under a wet cloth in a temperature of 70° to 80° F. The form was removed at the end of 24 hours and the wet cloths were not used after 5 or 6 days.

The 41 blocks made for these tests were broken when as nearly as possible 30 days old.

Pressure was applied by a cast iron plate 5 inches square and 1 inch thick concentric with the upper surface of the block and its edges parallel to the edges of the block. Each block was bedded

in quick setting plaster of paris. The compression plate was similarly bedded and the machine brought as quickly as possible to a pressure of 1000 pounds. The plate was again examined as to centering and bearing and the plaster allowed to set for 10 minutes, when a gradual pressure was brought to bear for the test. At the first appearance of a check or crack on the vertical face of the block a reading was taken and the test continued to a maximum.

See Table I for a result of the tests of the 19 concrete blocks, and Table II for the 13 mortar blocks.

Five blocks 10″ x 10″ x 6″ were made with concrete cores in the hope of getting material to work out the theory of failure. This was useless since the mortar and its concrete failed at so nearly the same value that no difference existed that could be depended upon.

The core was first made in form No. 1 (5″ x 5″ x 6″) and at the end of 24 hours it was well wet and the mortar added in form No. 3 (10 x 10 x 6). The blocks were then treated like the others. On breaking, however, these blocks failed at a very low figure, showing that, though union of mortar and concrete was good, it was the weakest point in the block.

See Table III for a result of the compound blocks.

TABLE I. CONCRETE BLOCKS.

No.	Date		Size	Total Stresses		Stresses per □″	
	Made	Broken		Initial	Maximum	Initial	Maximum
1	3: 3 : '03	4: 3 : '03	5″x 5″x6″	29300	31000	1172	1240
2	3: 3	4: 3	10 x10 x6	59350	78660	2374	3146
3	3: 3	4: 3	12 x12 x6	53090	67000	2124	2680
4	3: 5	4: 4	5 x 5 x6	38300	40600	1532	1624
5	3: 5	4: 4	8 x 8 x6	48600	72000	1944	2880
6	3: 5	4: 4	10 x10 x6	90830	110700	3633	4428
7	3: 5	4: 4	12 x12 x6	56000	82700	2240	3308
8	3: 6	4: 4	5 x 5 x6	27200	30650	1088	1226
9	3: 6	4: 4	8 x 8 x6	31350	56960	1254	2278
10	3: 6	4:13	10 x10 x6	45400	95400	1816	3816
11	3: 6	4: 4	12 x12 x6	60000	79620	2400	3185
12	3:10	4.13	5 x 5 x6	35450	37700	1418	1508
13	3:10	4:13	8 x 8 x6	56630	76710	2265	3068
14	3:10	4:13	10 x10 x6	62700	101100	2508	4044
15	3:10	4:13	12 x12 x6	92700	112800	3708	4512
16	3:18	4:20	5 x 5 x6	35000	40000	1400	1600
17	3:18	4:20	8 x 8 x6	50000	76000	2000	3040
18	3:18	4:20	10 x10 x6	80000	96000	3200	3840
19	3:18	4:20	12 x12 x6	82000	128000	3280	5120

TABLE II. MORTAR BLOCKS.

No.	Date		Size	Total Stresses		Stresses per □″	
	Made	Broken		Initial	Maximum	Initial	Maximum
1	3:11 : '03	4:13 : '03	5″x 5″x6″	30200	30200	1208	1208
2	3:11	4:13	8 x 8 x6	66100	69300	2644	2772
3	3:11	4:13	10 x10 x6	84000	88000	3360	3520
4	3:11	4:13	12 x12 x6	70000	104000	2800	4160
5	3:12	4:13	8 x 8 x6	57250	65420	2290	2617
6	3:12	4:13	10 x10 x6	61300	72000	2452	2880
7	3:12	4:13	12 x12 x6	74200	90500	2968	3620
8	3:13	4:13	5 x 5 x6	35200	36000	1408	1440
9	3:13	4:13	8 x 8 x6	64000	74000	2560	2960
10	3:13	4:13	10 x10 x6	76200	91350	3048	3654
11	3:13	4:13	12 x12 x6	91500	98560	3660	3942
12	3:16	4:20	5 x 5 x6	28000	30000	1120	1200
13	3:16	4:20	8 x 8 x6	50000	50000	2000	2000

TABLE III. COMBINATION BLOCKS.

No.	Date		Size	Total Stresses		Stresses per □″	
	Made	Broken		Initial	Maximum	Initial	Maximum
1	3:16 : '03	4:16 : '03	10″x10″x6″	42000	45400	1680	1816
2	3:16	4:16	" " "	53000	53000	2040	2120
3	3:17	4:20	" " "	31000	44000	1240	1760
4	3:20	4:20	" " "	43000	46000	1720	1840
5	3:20	4:20	" " "	40700	40700	1628	1628

CONCLUSIONS.

From the experiments performed we may conclude:

1. The capacity of elements in compression is increased by the addition of external elements, which are not in compression save by laterally transmitted forces.

2. The curve of total areas and pressures is convex, therefore the total capacity of the block can never be higher than its capacity under uniformly distributed loading. A concave curve would show a capacity increasing faster than the area and therefore an increasing total capacity which we do not find in the experiments.

3. The curve is convex, therefore there is a limit to the increasing capacity of the elements in compression. Evidently this limit is the pressure at which the particular mixture in question would disintegrate without changing the form of the whole mass.

4. The curve of the capacities of compression elements platted to the area of external material shows that the capacity of compressed elements increases fairly closely with the vertical

rectangular cross section of elements external to them; but follows a little more closely perhaps the areas outside the planes of cleavage at failure. Even the latter is far from a straight line.

5. It is evident that to develop the greatest capacity of concrete in compression it is necessary to support or confine it; and it is equally evident from general considerations that additional concrete is not the most efficient or reliable material for this purpose.

6. On the other hand, where, from consideration of the appearance, or ultimate foundation bearing, large concrete areas are called upon to bear concentrated loads the safe bearing value of the surface may be taken at from three to six times as great as on a uniformly loaded block of the same material.

ABSTRACT OF THESIS ON

EFFECT OF FREEZING ON CONCRETE.

P. I. GUNSTAD, C. E. '01.

(Abstract made by J. C. Holland, '04.)

Mr. Gunstad in substance has the following to say:

Object.—The object of these experiments is to study the effects of freezing on both natural and Portland cement concrete as compared with concrete which is not frozen. A study is also made of the effect of different amounts of water both in the frozen and unfrozen concrete.

Lines of Investigation.—The lines of investigation are as follows:

I. *General Plan.*—The relative strength of stiff and sloppy mortar in concrete; using various proportions of materials making similar cubes for each kind of mortar. These cubes are divided into two groups,

1. Cubes not allowed to freeze.
2. Cubes allowed to freeze as soon as made.

Group 2 is further divided into two groups. (a) Cubes tested soon after thawing out; (b) cubes tested at the same time similar cubes in group 1 are tested.

II. *Preliminary Steps.*—1. Weigh a given volume of stone, sand, and cement (materials loose as in practice).

2. Measure the volume of voids in stone.

3. Make mortar 1 : 1; 1 : 2; 1 : 3 (by weight) in given quantities sufficient for a few briquettes each.

(a) Make mortar dry (no water).

(b) Make mortar stiff (add a given per cent of water).

(c) Make mortar sloppy (add a given per cent of water).

Measure the volume of mortar as made above. From the known weights of sand, cement and water in each mixture calculate the volume of material used. Find the per cent of final volume of mortar, with the sum of the volumes of ingredients. This will show the per cent of shrinkage.

4. Knowing the per cent of shrinkage for the several mortars, calculate the weight of sand, cement and water for a given volume of stone (say 1 cu. ft. of stone) when the mortar (a) just fills the voids; (b) 10% excess; (c) 20% excess, etc.

This will establish the theoretical proportions for the given materials and the several kinds of mortar.

5. Make a number of briquettes with the mortar used in (3) for tensile tests; also neat of each kind.

6. From (4) determine the practical proportions to be used in making the cubes.

Materials.—The cements used are Atlas, Portland and Mankato natural. The sand used is common sand such as is used in ordinary concrete construction, being clean and sharp. The stone is a limestone kindly furnished by the Langdon Stone Co.

Weights of Materials.—Stone, 1 cu. ft., 91 lbs.; Portland Cement, 1 cu. ft., 86 lbs.; Sand, 1 cu. ft., 87 lbs.; Natural Cement, 1 cu. ft., 63 lbs.

Below is a table showing the results of the tests of the cubes when tested to destruction: Cubes from 19 to 36 inclusive are made of natural cement, all others of Portland.

No.	Age in Days When Broken	Proportions	Consistency	Where Made	Strength in lbs. per □″	% each is of strongest in that series	% each is of strongest of same consistency same proportions
1a	46	1 : 3 : 5	Sloppy	Inside	920	.....	.....
1	84	"	Stiff	Outside	1100	44.1	97.7
2	46	"	"	"	832	35.1	73.5
3	84	"	"	Inside	1132	45.1	100
4	46	"	Sloppy	Outside	456	18.2	18.2
5	84	"	"	"	936	37.3	37.3
6	86	"	"	Inside	2512	100	100
7	84	1 : 3 : 7	Stiff	Outside	988	49.4	63.5
8	44	"	"	"	638	31.9	41
9	84	"	"	Inside	1556	77.8	100
10	43	"	Sloppy.	Outside	432	21.6	21.6
11	83	"	"	"	816	40.8	40.8
12	83	"	"	Inside	2000	100	100
13	82	1 : 3 : 8	"	Outside	956	48.7	48.7
14	51	"	"	"	926	47.2	47.2
15	85	"	"	Inside	1960	100	100
16	50	1 : 3 : 9	"	Outside	800	43.2	48.6
17	80	"	"	"	786	42.5	47.8
18	80	"	"	Inside	1645	88.9	100
19	80	1 : 2 : 6	Stiff	Outside	15	2.2	2.2
20	49	"	"	"	328	48.1	40.1
21	80	"	"	Inside	682	100	100
22	47	"	Sloppy	Outside	204	29.9	33.6
23	78	"	"	"	31	4.5	5.1
24	78	"	"	Inside	608	89.1	100
25	.....	1 : 2 : 7	Stiff	Outside	Broke	n in han	dling
26	47	"	"	"	221	35.1	35.1
27	78	"	"	Inside	630	100	100
28	80	"	Sloppy	Outside	163	25.9	31.9
29	.....	"	"	"	Broke	n in han	dling
30	78	"	"	Inside	510	80.9	100
31	76	1 : 2 : 5	Stiff	Outside	302	55.7	55.7
32	46	"	"	"	298	55	55
33	76	"	"	Inside	542	100	100
34	.....	"	Sloppy	Outside	Broke	n in han	dling
35	76	"	"	"	88	16.2	22.9
36	76	"	"	Inside	384	70.8	100
37	76	1 : 3 : 9	Stiff	Outside	1082	58 5	58.5
38	45	"	"	"	998	53.9	53.9
39	76	"	"	Inside	1850	100	100

Cubes.—The cubes made are of the uniform size of 10″ on an edge and all the cubes, with one exception, are made in sets of three each. Two cubes out of each set were carried into the open air as soon as made and the other one kept damp inside.

The cubes outside were subjected to February and March weather and only twice did the temperature get down as low as 14° below zero, but they remained frozen all the time.

Conclusions.

1. Portland cement concrete does not disintegrate when made in freezing weather, but the surface is slightly cracked. The amount of surface cracking depends upon the consistency of the concrete. The strength is reduced by freezing.

2. Water is an important consideration in both frozen and unfrozen Portland cement concretes. (a) Sloppy concrete is stronger than stiff concrete when made and allowed to set inside. (b) Stiff concrete is stronger than sloppy concrete made and left outside to be frozen.

3. Natural cement concrete made and left outside disintegrates and is very weak. It is an unreliable material when frozen.

4. The amount of water is important with respect to concrete which will freeze as soon as made. Stiff concrete made and left to set inside is stronger than sloppy.

THE ELECTROSTATIC CAPACITY OF WIRES.

GEO. D. SHEPARDSON,

Prof. of Electrical Engineering, University of Minnesota

The electrostatic capacity of electrical conductors is of considerable importance in the case of long telephone, telegraph and electric power transmission lines, in which the strength and direction of the current vary with rapid pulsations or alternations.

The electrostatic capacity of the wires limits the speed with which submarine telegraph cables or long land lines may be operated. It limits the distance over which the telephone may operate through submarine, underground or aerial cables, and is the principal factor which limits long distance telephony to a distance at present about two thousand miles. In the case of long distance power transmission lines, which necessarily operate at high potentials, the current required for the electrostatic charging of the lines absorbs a very considerable output. For example, the Bay Counties Power Company in California, in transmitting power at 50,000 volts over a distance of 150 miles, finds that the electrostatic charge on the lines absorbs about 40 amperes, which is the full current output of a 2,000 kilowatt or 2,700 horse-power generator. When dealing with long distances, high frequencies or high voltages, electrostatic phenomena, therefore, come to have considerable importance, and it is desirable that the engineer should be able to calculate within reasonable limits the capacity of an existing or contemplated line.

The capacity of a wire depends upon its section and length, the character of the surrounding medium and the proximity of other conductors. In nearly all cases the conductor is of circular section, which fortunately is most convenient for electrostatic calculations. In most cases the surrounding medium is air, whose dielectric constant is taken as unity.

The arrangement of other conductors is subject to many variations.

Some of the more important cases will be considered as follows:

(1) A conductor within a concentric envelope;

(2) Two parallel wires in air;

(3) A single aerial wire with ground return;

(4) Two parallel wires in air as affected by the proximity of the earth;

(5) Three wires at vertices of an equilateral triangle.

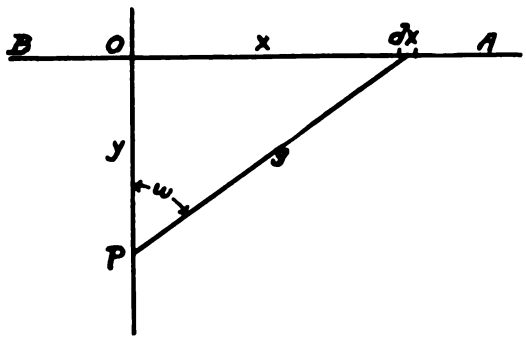
The C. G. S. electrostatic unit of quantity is defined as that quantity which repels an equal quantity at a distance of one centimeter in air with a force of one dyne. The force between two charges is directly proportional to the product of the quantities and is inversely proportional to the square of the distance between them. It also varies with the nature of the material between the two charges, being inversely proportional to a factor known as the "dielectric constant" or the "specific inductive capacity" of the material, that of air being taken as unity or the standard of reference. The force with which a quantity Q considered as concentrated at a point acts upon a unit charge at a distance D in a medium whose dielectric constant is K, is therefore,

$$f = \frac{Q}{K D^2}.$$

Suppose that a charge of Q units of electricity per unit length of wire is distributed along a wire whose length is great compared with its diameter. Consider first the force exerted upon a unit charge at any point by the charge which is distributed upon the whole length of the wire. Usually the diameter of the wire is small compared with the distances considered, so that the charge may be taken without great error as concentrated along the central axis of the wire. The charge upon an elementary length of the wire, dx, is $Q dx$. This exerts upon a unit charge at any point P a force

$$dF = \frac{Q dx}{K g^2} = \frac{Q\, dx}{K (x^2 + y^2)}$$

in which g is the distance between the point P and the element of wire under consideration, y is the perpendicular distance from the point P to the wire, and x is the distance from the element of wire to the foot of the perpendicular.



This force, dF, which acts along the line g, may be resolved into two components, a component parallel to the wire,

$$dF' = \frac{Q\, dx}{K(x^2+y^2)} \sin \omega = \frac{Q}{K} \frac{dx}{x^2+y^2} \frac{x}{(x^2+y^2)^{\frac{1}{2}}} = \frac{Q\, x\, dx}{K (x^2 + y^2)^{\frac{3}{2}}}$$

and a component perpendicular to the wire,

$$dF'' = \frac{Q\,dx}{K(x^2+y^2)}\cos\omega = \frac{Q}{K}\frac{dx}{(x^2+y^2)}\frac{y}{(x^2+y^2)^{\frac{1}{2}}} = \frac{Q\,y\,dx}{K(x^2+y^2)^{\frac{3}{2}}},$$

in which ω is the angle between the perpendicular and g.

The component dF' for any element at the right will be exactly balanced by an equal and opposite component of the force from an element at an equal distance at the left, so that the aggregate force parallel to the wire will be nil. Therefore, only the component dF'' perpendicular to the wire need be considered further. In the equation for dF'' we may substitute:

$$x = y\tan\omega$$
$$dx = y\sec^2\omega\,d\omega$$
$$x^2 + y^2 = y^2\sec^2\omega$$

and obtain as the total effective force due to an element of the charge,

$$dF'' = \frac{Q\,dx}{K\,g^2}\cos\omega = \frac{Q\,d\omega}{K\,y}\cos\omega.$$

To obtain the total force due to all the elements of the charge Q on the wire upon the unit charge at the point P, take the summation of the forces due to all the elements on the wire from a great distance to the right, where $\omega = +\frac{\pi}{2}$ to a great distance to the left, where $\omega = -\frac{\pi}{2}$

$$F = \frac{Q}{Ky}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}}\cos\omega\,d\omega = \frac{Q}{Ky}\sin\omega\Big]_{-1}^{+1} = \frac{2Q}{K\,y}$$

The difference of potential between two points is defined to be the work required to move a unit charge from one point to the other. The work is the product of force by space. When the force varies in different parts of the space involved, the total work is the integral or summation of the force at each point by the elementary distance through which it may be considered as practically uniform. The difference of potential between a charged conductor and a point at distance D is then the integral or summation of the work done in moving a unit charge from a point infinitely near the surface of the charged conductor to the point in question, or

$$V_D = \int_r^D F\,dy = \int_r^D \frac{2Q}{K\,y}\,dy = \frac{2Q}{K}\log_e y\Big]_r^D$$
$$= 2Q(\log_e D - \log_e r) = 2Q\log_e\frac{D}{r}$$

in which r is the radius of the conductor, or the distance from the surface to the center, it being presumed that the net effect

of the charge on the conductor is as though the whole charge were concentrated along the center line or axis.

CAPACITY BETWEEN CONCENTRIC CONDUCTORS

A comparatively simple case is that of an insulated conductor surrounded by a conducting sheath, such as a lead covered cable, or an insulated wire surrounded by water or damp earth. Let r be the radius of the interior conductor, R the internal radius of the outer conductor, K the dielectric constant of the intervening insulation, and Q the charge on unit length of the inner conductor. The difference of potential between the surface of the inner conductor and the outer conductor is the work done in moving a unit charge from a point infinitely near one surface to a point infinitely near the other surface. This work is the sum of the work done against the charge on the inner conductor and of that done against the charge on the outer. The work done in moving a unit charge from one surface to the other against the charge on the inner conductor is, as shown above,

$$V = 2\,Q\,\log_e \frac{R}{r}.$$

The work done against the charge on the outer conductor is zero in this case, for it may be shown that a charge uniformly distributed over a sphere or cylinder has no effect upon a charge within, the forces in all directions being mutually balanced. Therefore the work done against the charge on the inner conductor is the total work done in moving a unit charge from one surface to the other. Since the inner and outer conductors are concentric, the distance between the surfaces is the same in every direction and the above expression for the work is true in every direction between the surfaces and is general.

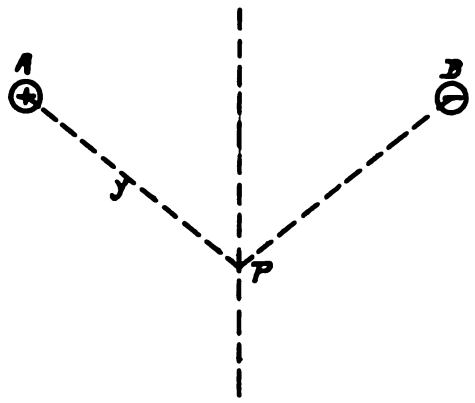
The capacity of a conductor, or the capacity between two conductors is by definition equal to the quantity of charge divided by the difference of potential. Therefore, the capacity between the inner and outer surface for each unit length, and in electrostatic units is

$$C = \frac{Q}{V} = \frac{Q}{2\,Q\,\log_e \frac{R}{r}} = \frac{1}{2\,\log_e \frac{R}{r}}.$$

CAPACITY BETWEEN TWO PARALLEL WIRES

In the case of two parallel wires of radius r, separated by a distance D, and carrying equal and opposite charges, the capacity may be considered as consisting of two capacities between the respective wires and a plane of zero potential midway between them. Let A be a long wire with a positive charge uniformly distributed along its length, and let B be a second

wire parallel to A and having an equal negative charge uniformly distributed along its length.



The work done in bringing a unit positive charge from any point P at a distance p in the neutral plane to a point infinitely near to the surface A, is the work done against the repulsion of the positive charge on A plus the work done against the attraction of the charge on B.

$$V_A = 2Q \int_r^p \frac{dy}{y} + 2Q \int_p^{D-r} \frac{dy}{y} = 2Q \left(\log_e \frac{D-r}{p} + \log_e \frac{p}{r}\right)$$

$$= 2Q \log_e \frac{D-r}{r} \cong 2Q \log_e \frac{D}{r}.$$

Similarly, the work done in pushing a positive charge from a point infinitely near the surface of B to the neutral plane is that done against the attraction of B plus that due to the repulsion of the charge on A.

$$V_B = 2Q \int_{r'}^{p'} \frac{dy'}{y'} + 2Q \int_{p'}^{D-r'} \frac{dy'}{y'} = 2Q \left(\log_e \frac{p'}{r'} + \log_e \frac{D-r'}{p'}\right)$$

$$= 2Q \log_e \frac{D-r'}{r'}.$$

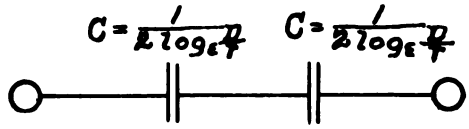
When the two wires are of the same size, $r' = r$; also r and r' are small in comparison with D, at least for aerial circuits; therefore we may write

$$V_B \cong 2Q \log_e \frac{D}{r}.$$

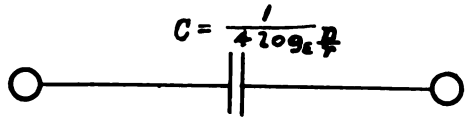
The capacity between either wire and the neutral plane is thus

$$C = \frac{Q}{V_A} = \frac{Q}{V_B} = \frac{Q}{2\,Q\,\log_e \frac{D}{r}} = \frac{1}{2\,\log_e \frac{D}{r}}$$

in which C is electrostatic units per centimeter length of wire. This is equivalent to two condensers in series between A and B, each of the capacity derived above.



These may be replaced by a single condenser whose capacity is half of one of the two. Thus:



$$C = \frac{Q}{V_A - V_B} = \frac{Q}{2\,Q\,\log_e \frac{D}{r} + 2\,Q\,\log_e \frac{D}{r}} = \frac{1}{4\,\log_e \frac{D}{r}}$$

The absolute electrostatic units of capacity may be changed to practical electromagnetic units by dividing by the square of the velocity of light and multiplying by 10^9; the Naperian logarithm is changed to the common logarithm by multiplying by 2.302. Hence

$$C = \frac{10^9}{4 \times (3 \times 10^{10})^2 \times 2.302\ \log_{10} \frac{D}{r}}.$$

$$= \frac{1208 \times 10^{-10}}{\log_{10} \frac{D}{r}} \text{ farads per centimeter,}$$

$$= \frac{.0000001208}{\log_{10} \frac{D}{r}} \text{ microfarads per centimeter length of line,}$$

$$= \frac{.003681}{\log_{10} \frac{D}{r}} \text{ microfarads per 1000 feet,}$$

$$= \frac{.01942}{\log_{10} \frac{D}{r}} \text{ microfarads per mile.}$$

(Note that Table III in Foster's Handbook, page 111, is wrong in giving values with above constants as capacity per wire.)

The capacity between either wire and the neutral plane is double the amount indicated by the above coefficients.

CAPACITY BETWEEN AN AERIAL WIRE AND THE GROUND.

Since the potential of the earth is taken as the basis of reference, the surface of the earth may be considered as the neutral plane in the case of an overhead wire. The height, h, above the ground may then be considered as equivalent to the distance between either wire and the neutral plane of the preceding case. We may then write

$$C = \frac{1}{2 \log_e \frac{D}{r}} = \frac{1}{2 \log_e \frac{2h}{r}} = \frac{1}{2 \log_e \frac{4h}{d}}$$

in which r is the radius and d the diameter of the wire.

An aerial wire may thus be considered as part of a circuit whose return wire is at a distance $2h$ below the wire or at a distance h below the surface of the earth. This supposititious wire is called the electrical "image" of the actual aerial wire.

The formula may be reduced to more convenient terms as before:

$$C = \frac{1}{2 \log_e \frac{2h}{r}} \quad \text{electrostatic units per centimeter,}$$

$$= \frac{2416 \times 10^{-16}}{\log_{10} \frac{2h}{r}} \quad \text{farads per centimeter,}$$

$$= \frac{.0000002416}{\log_{10} \frac{2h}{r}} \quad \text{microfarads per centimeter,}$$

$$= \frac{.007362}{\log_{10} \frac{2h}{r}} \quad \text{microfarads per 1000 feet,}$$

$$= \frac{.03884}{\log_{10} \frac{2h}{r}} \quad \text{microfarads per mile.}$$

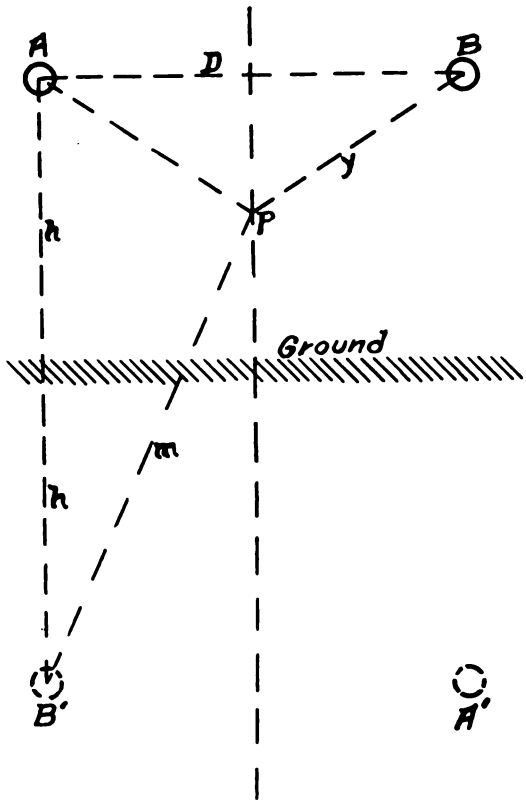
The capacity is affected by the proximity of other conductors and by the insulating supports.

CAPACITY BETWEEN AERIAL WIRES AFFECTED BY THE EARTH.

The effect of the presence of the earth upon the capacity between aerial wires may be illustrated by analyzing the case of two wires of radius r, separated by a distance D and at a height h above the ground.

In moving a unit positive charge from any point P in the neutral plane midway between the two wires to a point infinitely near the surface of either wire, work is done against the charges on each of the wires and also against their images which are below the surface of the earth a distance equal to the height

of the actual wires. Suppose that wire A is charged positively, its image B' negatively, wire B negatively and its image A'



positively. The work done in moving a unit positive charge from any point in the neutral plane against the various charges is

$$V_A = 2\,Q\int_r^{\rho}\frac{dy}{y}\,;\quad V_B = 2\,Q\int_{\rho}^{D-r}\frac{dy}{y}\,;$$

$$V_{B'} = 2\,Q\int_m^{2h-r}\frac{dy}{y}\,;\quad V_{A'} = -2\,Q\int_m^{\sqrt{(D-r)^2+(2h)^2}}\frac{dy}{y}\,.$$

The total work is the sum, or

$$V = 2\,Q\left\{\log_e\frac{\rho}{r}+\log_e\frac{D-r}{\rho}+\log_e\frac{2h-r}{m}-\log_e\frac{\sqrt{(D-r)^2+(2h)^2}}{m}\right\}$$

$$= 2\,Q\left\{\log_e\frac{D-r}{r}-\log_e\frac{[(D-r)^2+(2h)^2]^{1/2}}{2h-r}\right\}.$$

Since r is generally quite small as compared with $2h$ or D, we may write

$$V = 2Q\left[\log_e \frac{D}{r} - \log_e \frac{(D^2 + 4h^2)^{1/2}}{2h}\right]$$

$$= 2Q\left\{\log_e \frac{D}{r} - \log_e\left[1 + \left(\frac{D}{2h}\right)^2\right]^{1/2}\right\}.$$

An equal amount of work is done in moving the unit charge from a point infinitely near the wire B to the assumed point P, so that the total work done in moving a unit charge from one wire to the other is

$$V = 4Q\left\{\log_e \frac{D}{r} - \log_e\left[1 + \left(\frac{D}{2h}\right)^2\right]^{1/2}\right\},$$

The capacity is then,

$$C = \frac{Q}{V} = \frac{1}{4\log_e \frac{D}{r} - 4\log_e\left[1 + \left(\frac{D}{2h}\right)^2\right]^{1/2}}$$

Comparing this expression for that previously obtained for the capacity between two wires without considering the earth,

$$C = \frac{1}{4\log_e \frac{D}{r}},$$

it is seen that the presence of the earth increases the capacity between the two wires, the increase being greater as the wires are farther apart and less as they are higher above the earth. This is of importance in the design of telephone lines, which should be on high poles. The presence of grounded wires on a pole line has the effect of bringing the earth closer to the other wires, and thereby increasing their capacity.

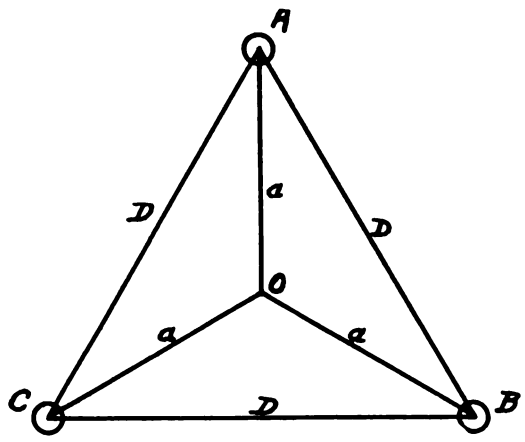
CAPACITY OF A THREE PHASE CIRCUIT.

The capacity of wires at the apices of an equilateral triangle, or rather at the edges of a triangular prism, is of importance from the fact that most of the long distance transmission plants use three-phase current carried on wires so arranged. The currents and pressures are 120 degrees apart, so that the sum of the currents in the three wires is zero and no fourth wire is required as common return. If the three wires are at the apices of an equilateral triangle, the center of the triangle fixes the line of zero potential by symmetry.

If Q be the maximum positive charge on unit length of wire, then assuming that the current and pressure vary in accordance with sine law, the charges on the wires at any instant will be

$q_A = Q\sin\omega$; $q_B = Q\sin(\omega - 120°)$; $q_C = Q\sin(\omega - 240°)$

Letting a represent the distance from any wire, say A, to the center, and D the distance between centers of wires, the work done in moving a unit positive charge from the line of zero



potential to wire A is the sum of the work done against the charges on the several wires, or,

$$V = V_A + V_B + V_C$$

$$= 2\,q_A \log_e \frac{a}{r} - 2\,q_B \log_e \frac{D}{a} - 2\,q_C \log_e \frac{D}{a}$$

$$= 2\,Q\left\{\sin\omega \log_e \frac{a}{r} - [\sin(\omega - 120°) + \sin(\omega - 240°)]\log_e \frac{D}{a}\right\}$$

Substituting

$$\sin(\omega - 120°) = \sin\omega \cos 120° - \cos\omega \sin 120°$$

$$= -\tfrac{1}{2}\sin\omega - (\tfrac{3}{4})^{\frac{1}{2}}\cos\omega,$$

$$\sin(\omega - 240°) = \sin\omega \cos 240° - \cos\omega \sin 240°$$

$$= -\tfrac{1}{2}\sin\omega + (\tfrac{3}{4})^{\frac{1}{2}}\cos\omega,$$

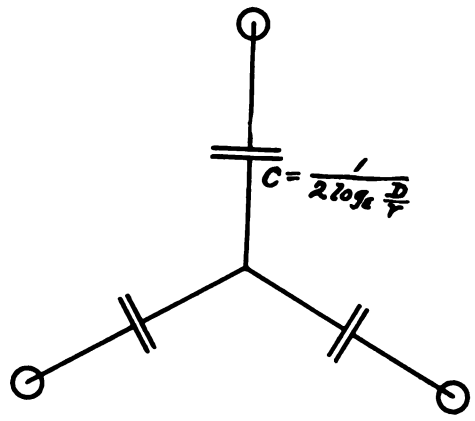
we obtain

$$V = 2\,Q\left\{\sin\omega \log_e \frac{a}{r} - \left[\left(-\tfrac{1}{2}\sin\omega - \left(\frac{3}{4}\right)^{\frac{1}{2}}\cos\omega\right) + \left(-\tfrac{1}{2}\sin\omega - \left(\frac{3}{4}\right)^{\frac{1}{2}}\cos\omega\right)\right]\log_e \frac{D}{a}\right\}$$

$$= 2\,Q\left[\sin\omega \log_e \frac{a}{r} + \sin\omega \log_e \frac{D}{a}\right]$$

$$= 2\,Q \sin\omega \log_e \frac{D}{r}.$$

Then the capacity between any wire and the neutral line is



$$C = \frac{q}{V} = \frac{Q \sin \omega}{2\, Q \sin \omega \log_e \frac{D}{r}} = \frac{1}{2 \log_e \frac{D}{r}} \text{ electrostatic units,}$$

$$= \frac{.00000002416}{\log_{10} \frac{D}{r}} \text{ microfarads per centimeter length of wire,}$$

$$= \frac{.007362}{\log_{10} \frac{D}{r}} \quad \text{microfarads per 1000 feet,}$$

$$= \frac{.03884}{\log_{10} \frac{D}{r}} \quad \text{microfarads per mile.}$$

THE SOLUTION OF PROBLEMS IN SPIRAL GEARING.

E. C. OLIVER,

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A number of methods have been proposed by different designers for the solution of problems in spiral gearing. These solutions have been mostly, if not all, graphical methods, the accuracy of which depends upon the ability of the workman to determine intersections and scale distances exactly. This may give results sufficiently close for ordinary work, especially since spiral gears are extremely accommodating in their nature and will run smoothly if not constructed theoretically correct.

However, if accuracy is attainable with no more labor than is otherwise necessary, there is no good reason why such a method should not have a place and for this reason the following is offered as a simple and accurate method for the solution of any problem in spiral gearing. It requires very little mathematical work and no construction.

In any pair of spiral gears let

D_1 be diameter of driving gear;

D_2 be diameter of driven gear;

N_1 be number of teeth in driving gear;

N_2 be number of teeth in driven gear;

P_1 circular pitch of teeth in driving gear;

P_2 circular pitch of teeth in driven gear;

a_1 angle of teeth in driving gear;

a_2 angle of teeth in driven gear.

(1) We know that for spiral gears the sum of the angles of the teeth (a_1+a_2) must equal the angle between the shafts.

(2) In any pair of gears the number of teeth in the gears is inversely proportional to the speed of the shafts.

(3) In any gear the circular pitch is directly proportional to the diameter of the gear when the number of teeth is constant and inversely proportional to the number of teeth when the diameter is constant. We may state this relation numerically for either gear of a pair as follows:

$$P_1 = \frac{\pi D_1}{N_1} \text{ and } P_2' = \frac{\pi D_2}{N_2}$$

from which we have

$$\frac{P_1}{P_2} = \frac{D_1 N_2}{D_2 N_1} \qquad (a)$$

Figure 1 represents a tooth and space on the face of a spiral gear, if $Pn = ab$ be the normal pitch, $P' = ac$ be the circular pitch of the gear and a the angle which the tooth makes with the axis of the gear then $P' = P_n \sec a$.

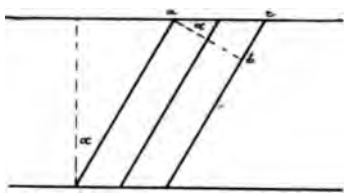

Fig. 1

Applying this relation to the pair of gears given in the notation above,

$$P_1 = P_n \sec a_1$$
$$P_2 = P_n \sec a_2$$

also

$$\frac{P_1}{P_2} = \frac{P_n \sec a_1}{P_n \sec a_2} \qquad (b)$$

Substituting in (a),

$$\frac{P_n \sec a_1}{P_n \sec a_2} = \frac{D_1 N_2}{D_2 N_1} \qquad (c)$$

D_1 and D_2 may be selected any reasonable amounts and are usually determined by constructive conditions, as in a gas engine it may be desirable to make D_1 equal to or greater than D_2 in order to go over a comparatively large crank shaft. $D_1 + D_2$ is of course equal to twice the center distance of the shafts.

SOLUTION WITH VARIABLE CENTER DISTANCE.

The problem now resolves itself into the selection of a pair of angles the sum of which is equal to the angle between the shafts and $\sec a_1 = C \sec a_2$ where C is the constant just determined

$$= \frac{D_1 N_2}{D_2 N_1}$$

This would determine our pair of gears, were it not for the fact that we must use spur gear cutters for the teeth, and our normal pitch, Pn, must correspond to the circular pitch of such a cutter as we can obtain.

Since $P_1 = P_n \sec a_1$ and $N = \frac{\pi D_1}{P_1'}$ then $\frac{\pi D_1}{P_1'}$ must be a whole number and if it does not chance to come out a whole number D_1 must be altered so that it will.

Let us solve a pair of gears that are to be used to drive the cam shaft of a four cycle gas engine in which the angle

between the shafts is 90°, the center distance about 6 inches and the diametrical pitch of the cutters 6. The gears are to be approximately the same diameter. We have from above,

$$\frac{\sec a_1}{\sec a_2} = \frac{D_1 N_2}{D_2 N_1} = \frac{1 \times 2}{1 \times 1}$$

or $\sec a_1 = 2\sec a_2$. This equation is satisfied when $a_1 = 63° 26'$ and $a_2 = 26° 34'$.

$P_n = \frac{\pi}{6} = .5236$ and

$P_1 = .5236 \times \sec a_1 = .5236 \times 2.2359 = 1.171''$.

$N_1 = \frac{\pi 6}{1.171} = 16.1$.

D_1 must be altered to make $N_1 = 16$. Then

$$D_1 = \frac{16 \times 1.171}{\pi} = 5.96''$$

D_2 will also be 5.96″ and the center distance of the shafts will be .04″ closer than was intended.

In designing a machine this can usually be allowed for, and is probably the easiest way out of the difficulty.

SOLUTION FOR UNCHANGED CENTER DISTANCE.

If it is not possible or desirable to change the center distance, the problem may still be solved without resorting to cut and try methods or in any way impairing the accuracy of the teeth.

There are in fact several solutions for such a problem, depending on the number of teeth we choose for the driver, but where we have certain conditions laid down, as in the preceding problem (that the diameters of the gears be approximately equal), there is always one number of teeth which will most nearly fulfill the conditions.

Thus in the first solution it was determined that a driver with 16 teeth was almost right and so if we assume this number of teeth for the driver and solve for the diameters, making $\frac{D_1 + D_2}{2}$ equal to the center distance, it will satisfy our conditions exactly.

From (*c*) $N_1 = \frac{\pi D_1}{P_n \sec a_1}$ (*d*)

$$N_2 = \frac{\pi D_2}{P_n \sec a_2}$$

Since π and Pn are constant, and we assume N_1 and N_2

to be constant, we may change these formulæ to the following form:

$$D_1 = C_1 \sec a_1. \qquad (e)$$
$$D_2 = C_2 \sec a_2.$$

where $C_1 = \frac{N_1 P_n}{\pi}$ and $C_2 = \frac{N_2 P_n}{\pi} = \frac{N_2}{N_1} C_1$

Since the center distance is to be constant, the sum of the diameters of the gears $D_1 + D_2 = Y$ or $D_2 = Y - D_1$
Substituting this value for D_2 in (e) we have $D_1 = C_1 \sec a_1$.

$$Y - D_1 = C_2 \sec a_2 \qquad (f)$$

Transposing the second equation,

$$D_1 = Y - C_1 \frac{N_2}{N_1} \sec a_2$$

Combining the equations,

$$C_1 \sec a_1 = Y - \left(C_1 \frac{N_2}{N_1} \sec a_2 \right) \text{ or}$$

$$\frac{Y}{C_1} = \sec a_1 + \frac{N_2}{N_1} \sec a_2$$

In this equation we know that $a_1 + a_2$ is the angle between the shafts and we know all the constants, so that the solution as before consists of taking from a table of secants two angles bearing the above relation.

Applying the solution to the problem already stated,

$$Y = 12'', \quad N_1 = 16, \quad N_2 = 32, \quad a_1 + a_2 = 90^\circ$$
$$P_n \text{ for 6 pitch} = .5236$$
$$C_1 = \frac{16 \times .5236}{3.1416} = 2.67 \qquad \frac{N_2}{N_1} = 2$$

$$\text{then } \frac{12}{2.67} = \sec a_1 + 2 \sec a_2$$

This equation is satisfied when $a_1 = 63^\circ\ 48'$
and $a_2 = 26^\circ\ 12'$

From (f),

$D_1 = 2.67 \times 2.265 = 6.04.$
$D_2 = 2 \times 2.67 \times 1.1145 = 5.96.$

SUMMARY.

Given,

a_0 = angle between shafts.

$\frac{Y}{2}$ = distance between centers

D_1 and D_2 or $\frac{D_1}{D_2}$ = ratio of diameters

P_n = normal pitch of cutter.

$\frac{N_2}{N_1}$ = speed ratio

Solve $\sec a_1 = C \sec a_2$ where $C = \frac{D_1}{D_2} \times \frac{N_2}{N_1}$

and $N_1 = \frac{\pi D_1}{Pn \sec a_1}$

If N_1 comes fractional, drop fraction and solve,

$$D_1 = \frac{N_1 Pn \sec a_1}{\pi}$$

and

$$D_2 = \frac{N_2 Pn \sec a_2}{\pi}$$

$$Y = D_1 + D_2 \text{ and } \frac{Y}{2} = \frac{D_1 + D_2}{2}$$

For unchanged center distance solve,

$$\frac{Y}{C_1} = \sec a_1 + \frac{N_2}{N_1} \sec a_2 \text{ where } C_1 = \frac{N_1 Pn}{\pi}$$

N_1 being obtained from previous solution.

Then,

$$D_1 = C_1 \sec a_1$$

$$D_2 = C_1 \frac{N_2}{N_1} \sec a_2$$

The length or pitch of spiral for either gear, $l = \pi D_1 \tan a_1$, and the cutter of a given pitch which would give us the correct shape of space for the driver is the one used in cutting a spur gear having a number of teeth $N_0 = N_1 \sec^3 a_1$, and for the driver gear $N_2 \sec.^3 a_2$.

One more solution is given in which the angles and speed ratios are not taken as simple as in the first,

Let a_0 be 72°

Y/2 be $7\frac{1}{2}''$

$D_1 = 1\frac{1}{2} D_2$, $D_1 = 9$, $D_2 = 6$

P_n for 6 pitch = .5236

$N_2/N_1 = 1\frac{3}{4}$

Following the method outlined

$C = 1\frac{1}{2} \times 1\frac{3}{4} = \frac{21}{8}$

sec. $a_1 = \frac{21}{8}$ sec. a_2, $a_1 + a_2 = 72^\circ$

$a_1 = 64^\circ\ 40'$ and $a_2 = 4^\circ\ 20'$

sec $a_1 = 2.6316$, sec $a_2 = 1.0029$

$$N_1 = \frac{\pi 9}{.5326 \times 2.6316} = 20.52 \text{ teeth.}$$

Use 20 teeth, because $N_2 = 1\frac{3}{4}\ N_1$, $N_2 = 35$

$$D_1 = \frac{20 \times .5326 \times 2.6316}{\pi} = 8.92$$

$$D_2 = \frac{35 \times .5326 \times 1.0029}{\pi} = 5.95$$

$$\text{Distance between centers} = \frac{8.92 + 5.95}{2} = 7.435$$

If the center distance is to be constant

$$C_1 = \frac{20 \times .5236}{3.1416} = 3\tfrac{1}{3}$$

$$\frac{Y}{C_1} = \frac{15}{3\frac{1}{3}} = 4\tfrac{1}{2} = \sec a_1 + 1\tfrac{3}{4} \sec a_2$$

This equation is satisfied when

$$a_1 = 68^\circ\ 39' \text{ and } a_2 = 3^\circ\ 21'$$

$$\sec a_1 = 2.7468, \quad \sec a_2 = 1.0017$$

$$D_1 = C_1 \sec a_1 = 3\tfrac{1}{3} \times 2.7468 = 9.156$$

$$D_2 = 3\tfrac{1}{3} \times 1\tfrac{3}{4} \times 1.0017 = 5.843$$

The pitch of spiral and number of cutter can be obtained as outlined above.

The only difficulty, if such it is, in the solution of the problem is that the secants for the necessary angles are not on the same page in the table, but this is trifling and in the great majority of problems, where the axes make an angle of 90°, the secants are not only on the same page, but, since the angles are complementary the secants are in the same line and it is but the work of a moment to find the correct angles.

THE UNIVERSITY HEALTH COMMITTEE AND ITS WORK.

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The University Health Committee came into existence at the time of a sudden and threatening typhoid epidemic in the community surrounding the University campus. When it was known that several students were ill with this disease, the President of the University appointed a committee to look into the condition of the drinking water used on the campus, the prevailing epidemic having been proven due to infected city water.

The committee first met on February 18th. It was found that with the exception of a period of two days (about three weeks before this meeting), city water had not been used for several months in any of the University buildings except in the Armory, which has no connection with the general water-supply system of the campus. At this time the city pumping station opposite Third Ave. S. E. was pumping badly polluted water into the mains on the east side of the river. This was considered by the committee a menace to the lives of the students and faculty residing on the East Side; accordingly a meeting was arranged with the water-committee of the city council on the following day and before sundown of that day orders had been given to shut down these pumps. Since that time it has been decided to permanently close this station, the use of which has cost Minneapolis many lives. At this meeting of February 18th it was decided to investigate the tanks which were used for supplying drinking water in the various buildings. These tanks were daily filled with spring water furnished by a local company. The water was cooled by ice stored out of doors unprotected. Chemical and bacteriological analyses were made of water from each tank; and also of water from the distributing wagon. Immediately after the tanks were sampled, orders were given that they should be sterilized with live steam once a week and that duplicate sets of drinking cups be supplied for each tank, the set not in use to be steam sterilized before being again used. The analyses above mentioned showed that the water as delivered upon the campus in the wagons was good, but that the water in the tanks was in two cases contaminated; the contamination being due to carelessness in handling water or ice, to the use of city water in tanks when the spring water was not delivered

for a day or two, to washing the tanks with city water or to the putting of refuse into tanks by thoughtless persons. During the cold weather, the ice is stored out of doors without any protection from dust or other sources of contamination.

The use of water from the artesian well for drinking purposes was next considered. Chemical and bacteriological analyses of this water were made, water being taken from the taps, from the cistern and from the delivery pipe at the well. The bacteriological analyses were extremely favorable. The chemical analyses showed high free ammonia and some nitrites, a combination usually looked upon as an indication of fresh sewage contamination. The absence of even a moderate amount of bacteria and of all sewage bacteria led to the conclusion in the writer's opinion that the organic matter indicated by the free ammonia is of vegetable rather than animal origin, and therefore harmless.

Another feature of the well, however, prevented the committee from advising its use as a source of drinking water, and that was that within five feet of the top of the casing and about one-half of a foot below the same, there runs a sewer from the Medical Hall and the Medical Chemical Laboratory. These buildings at times contain in the neighborhood of five hundred students, and the possibilities of a break in the sewer and the casing and back-water in the sewer would be too great to cause a feeling of security should the well be used. The well is said to be about 800 feet in depth and if properly sunk and operated, would, without doubt, give a supply of water unequalled for drinking purposes by any other available in the city. Why this sewer runs in this place and not directly to the outlet on the river bank back of the Library building cannot be accounted for by engineering precedent, as the latter location would cause the sewage to travel only one-third the distance it now does. Why the well was located close by the side of a sewer constantly used and which was punctured in sinking the well is likewise inexplicable.

The committee has recommended the removal of this sewer. The drainage of several of the buildings upon the campus is in an unsanitary condition and this has been considered by the committee.

Questions of sanitation are necessarily to some extent questions of cost, and costs have been considered, especially the cost of pumping as compared with the cost of buying spring water for the University. The money paid for spring water annually by the University represents an investment of $11,000 at 5% interest.

The matter which is of greatest interest to the mind of most students is not one of engineering importance, but as it has occupied a large share of the proceedings of the Committee, this article would not be complete if it were omitted. That is, the Students' Sick Benefit Fund. A petition was presented to the Committee signed by nearly one thousand students. It was as follows:

To the Faculty Board of Health:

We the undersigned, students of the University of Minnesota, being desirous that some definite action be taken with regard to providing a Students' Sick Benefit Fund for the relief of the sick, hereby petition your honorable body to consider the following plans and if necessary for the purpose of enforcement recommend them to the Board of Regents.

(1) Out of the fees paid by each student of the University fifty cents shall be set aside each semester to make up the Students' Relief Fund.

(2) This fund shall be at the disposal of a regularly constituted committee made up of faculty and student members and shall be used to defray the hospital and physicians' expenses of all students who may be ill during the college year.

(3) If deemed advisable, part of the fund may be set aside to employ a regular resident physician, whose duty it shall be to treat any cases of illness among the students reported to him.

Many physicians and the directors of several hospitals were consulted and the question discussed from various points of view. The petition was forwarded with additions and amendments to the Board of Regents.

This committee has been made a permanent one and the present members have been appointed for one year.

ABSTRACT OF THESIS ON

AN EXPERIMENTAL ALTERNATING CURRENT SERIES MOTOR.

J. C. VINCENT, E.E. '03.

Presented at the Minnesota Branch Meeting of the American Institute of Electrical Engineers, February 5, 1904.

(Abstract Made by F. C. Helms, '04.)

Of the many problems that have confronted the designing electrical engineers, that of producing a commercial series alternating current motor, has been one of the hardest and one may say, is still not completely solved. In 1893, the problem was attacked by many able electrical engineers, among whom were Deri, Blathy, Hutin, LeBlanc, Eickemeyer, and others. While these engineers solved some of the difficulties, their efforts did not result directly in a commercial machine. Interest in the motor seemed to lag until the announcement of the fact that the Westinghouse Company had contracted to build an electric line from Baltimore to Annapolis and that the motors under the cars were to be series alternating current motors. The fact that the problem has been attacked by a company whose reliability is usually unquestioned, gives promise of a commercial machine.

Reasons for the use of series alternating motors as means of propelling electric cars are important and convincing. In the case of the street railways, the direct current distribution at 550 volts has been very successful and satisfactory, but on long electric lines, the line drop and the cost of copper are prohibitive and limit the radius of distribution at 550 volts. This objection can be overcome by placing rotary converter sub-stations at convenient distances along the line, but this remedy is so expensive as to be prohibitive, also since the advent of heavy trains, the current at 550 volts required to pull the train is enormous and the collecting, by means of trolly or third rail, become serious problems. But the direct current series motor with the almost perfect series parallel control is the ideal motor for electric traction. The enormous starting torque, quick acceleration and the speed control leave but little to be desired.

In the design of the series of alternating current motor many difficulties must be overcome. A. C. Eborall, in an article in the *London Electrical Review,* Vol. 36, on "Single Phase A. C. Motors," gives the following on the series A. C. Motor:

"Owing to the fact that the direction of rotation of any ordinary direct current motor is the same irrespective of the direction of the current supplied to it, early attempts were made to

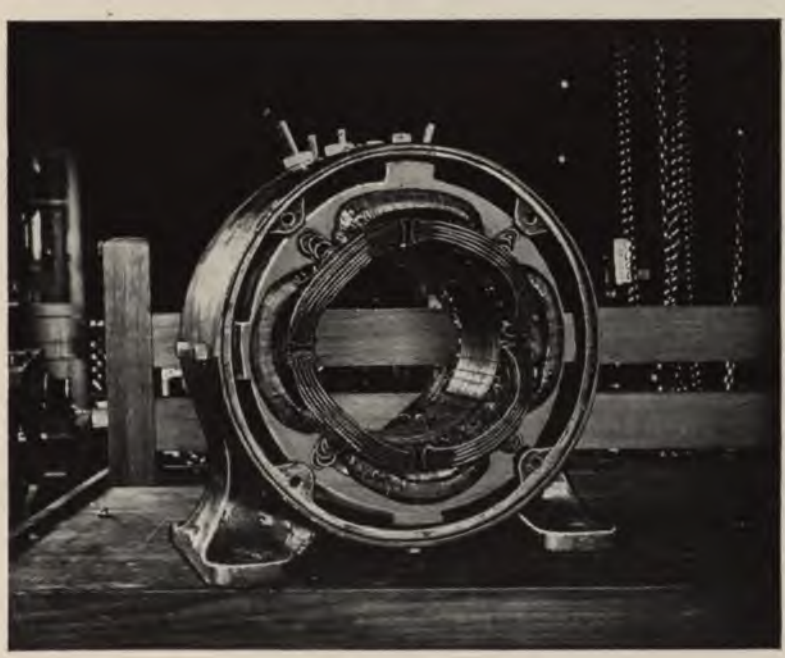
adopt it for use with an alternating current by laminating its field magnets. But this is not enough in itself, the crude form having many serious faults—the chief of them being:

"1. The hysteresis and eddy current loss may be very large.

"2. The motor takes a large current when running light or under-loaded.

"3. A large amount of magnetic leakage is generally present, more marked as the motor increases in size.

"4. A transformer action may take place between different layers in field magnet winding.



FRAME, FIELD CORE AND WINDING OF VINCENT'S EXPERIMENTAL MOTOR.

"5. As each section of the armature is short-circuited in turn by the brushes, this short-circuited section becomes the seat of very heavy induced currents, which react on the field magnet and also waste energy in heating the sections, and produce heavy sparking at the commutator.

6. "In the series motor, owing to the large amount of self-induction of the field magnet sufficient current cannot get through, the impedance being so great.

"All these troubles are greatly lessened by lowering the frequency of the supply current. It is easy to show that the output of a motor of this description is a maximum when the E. M. F. of self-induction is equal to the back E. M. F. generated by the motor. But it is only at quite low frequencies that such a condi-

tion can be attained at a reasonable speed; hence it is apparent that the lower the frequency the more efficient does the motor become. A coil placed at right angles to the field flux will neutralize the effect of armature reaction and hence the motor will have better speed regulation, and also would by its transformer action reduce the impedance of the armature coils."

Of the above faults, the short circuiting of the armature coils by the brushes and the impedance of the field and armature are the greatest and if completely overcome, the success of the motor is assured. Many attempts have been made to get rid of these faults and a few of the most important are outlined below.

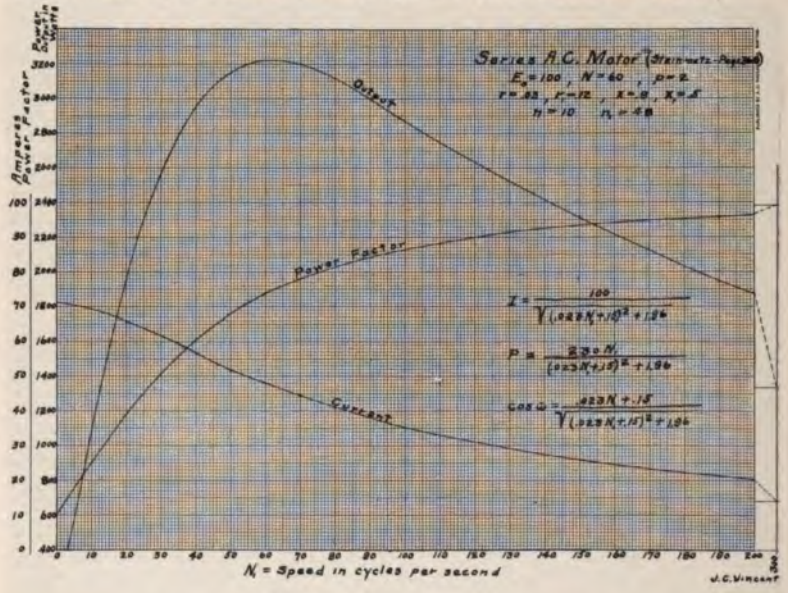


FIG. 1.—CURVES OF THEORETICAL MOTOR.

Guilbert in *La Lumiere Electrique* of July 29th, 1893, describes a "device of Messrs. Deri and Blathy for enabling a motor constructed like a direct current dynamo to be used on alternating current. It consisted essentially of inserting coils having resistance and self-induction between the junctions of the coils and commutator bars, instead of connecting the former to the latter directly. These coils can be wound on either the armature itself, or on a separate laminated iron core; in the former case they should be so placed that there is no induction in them due to the field, to the rotation of the armature, or to the periodic variation of the current. All these coils should be wound as nearly parallel as possible and next to one another,—the neighboring coils being wound in opposite directions. When one coil of the armature is short-circuited by the brushes, the effects of the induction in the two auxiliary coils are added to one another, whilst when the current to

the brushes passes through these coils in opposite directions, no counter induction is offered by the two coils." Thus by this means the current in the coils short-circuited by the brushes is choked down by the self-induction of these auxiliary coils to a reasonable and controllable value. But there still exists some short-circuit current and this effects the efficiency of the motor since it produces a back torque opposing the acting or forward torque. No means are stated of overcoming the impedance of the field and armature.

A scheme of Hutin and LeBlanc is described in Vol. 49 of *LaLumiere Electrique* for lessening the current due to the short-circuiting of the armature coils by the brushes. It consists of

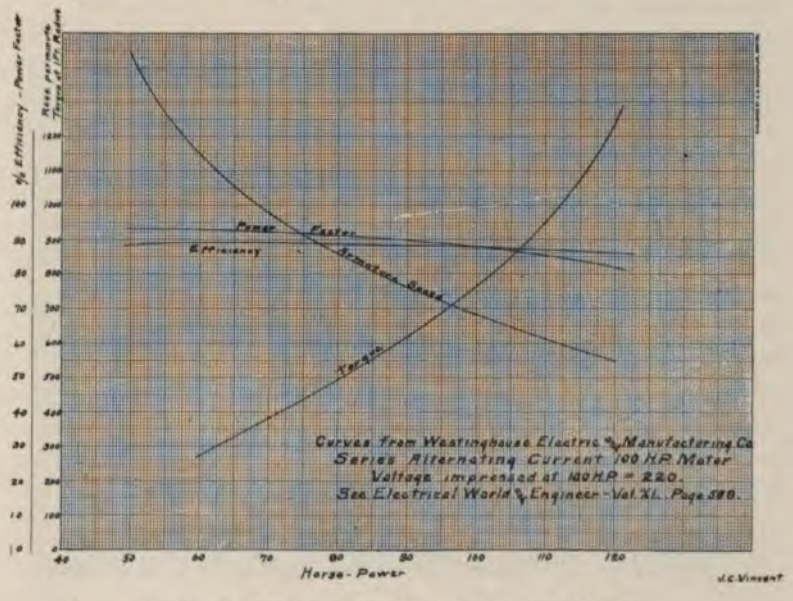


FIG. 2.—CURVES OF WESTINGHOUSE (LAMME) MOTOR.

making the armature leads of German silver of such size as will carry the full working current of the armature and of such resistance; i.e., of such length, that the short-circuit current will be limited to a reasonable value.

The most promising A. C. motor was devised by Eikemeyer. The motor is described very thoroughly by him in his U. S. Patents No. 567,119 and 664,733.

Steinmetz in his "Alternating Current Phenomena," Page 367, refers to a series A. C. Motor built by Eickemeyer. In Fig. I are reproduced curves computed from data of one of Eickemeyer's Motors. Steinmetz computes only to n=90 and the writer to ascertain facts computed to n=300. The main point to be noticed is the relation of the power factor to the speed—thus at synchronous speed the power factor is 74%; twice synchronous

speed, 90%; three times synchronous speed, 95.3%; and five times synchronous speed, 99%. This rise of power factor with speed is verified by the fact that the tangent of the angle of lag is equal to the ratio of the inductive E. M. F. to the sum of the resistance drop and the counter electromotive force of armature; i.e.:

$$\tan\ \omega = \frac{\text{Inductive E. M. F.}}{\text{R I + Counter E. M. F.}} = \frac{\omega\ \text{L I}}{\text{R I + C. E. M. F.}}$$

Thus from above formula, it is seen that as the speed increases and therefore an increase of counter E. M. F. and a decrease of current, tan ω will decrease and cos ω = power factor will increase.

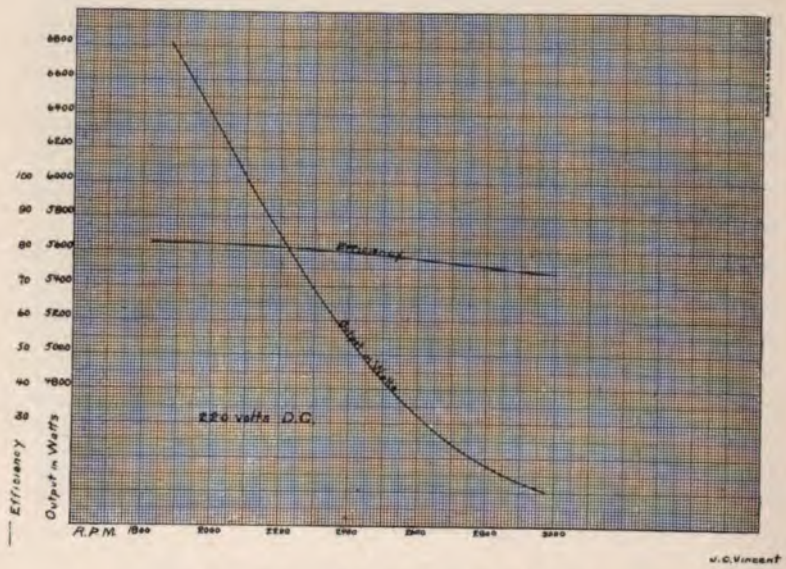


FIG. 3.—OPERATED ON DIRECT CURRENT.

Curves from the Westinghouse (Lamme) motor are given in Fig. 2. For further information regarding this motor see reference given on curve sheet in Fig. 2.

From the preceding paragraphs, it is seen that the following points must be observed in the design of a series A. C. Motor:

1. The armature self-induction must be neutralized by some scheme similar to Eickemeyer's.

2. There must be some means of reducing or preventing the short-circuit current in the armature coils.

3. The air gap must be kept small so that the turns on the field coil will be comparatively few. The use of perforated slots in both the armature and field increases the area of the air gap and reduces the reluctance.

4. Use a weak field (this is possible on account of field mentioned in (1) opposed to the armature cross field and the resulting non-distortion).

5. Design for high speed; i.e., working speeds to range from twice to 6 or 8 times synchronous speed.

6. Use the best of special iron in the armature and field and work it at a density about the same as that for transformers for that number of cycles per second.

7. Keep the number of bars under the brushes small.

8. Use a low frequency.

The writer in studying an article in the *Elektrotechnische Zeitschrift* of September 11th, 1902, by Frederich Eichberg, on "Deri's Compensated D. C. Machines," saw a possibility of using the scheme mentioned for a series A. C. Motor. The scheme is briefly: An ordinary armature is placed so as to revolve in a field ring similar to a two phase induction motor stator. One winding, usually a concentrated winding, though not necessarily so, is so placed as to form a main field and the second a uniformly distributed winding wound and connected so as to exactly neutralize or compensate for the armature cross field. Thus a small air gap can be used and the main field or "exciting winding" as it is so called, can be of a greatly lessened number of turns,—thus in ordinary machines, the ratio:

$$\frac{\text{Field-ampere-turns}}{\text{Armature-ampere-turns}} = \text{not less than 1.5, while by means of this winding the ratio becomes:}$$

$$\frac{\text{Field-ampere-turns}}{\text{Armature-ampere-turns}} = {}^1/_3.$$

Then a number of ampere turns are added to overcome the sparking due to the commutating coils moving in the fringing field.

This form D. C. Machine seems an ideal one for adapting to a series A. C. Motor. It is seen that the armature can be exactly compensated and that the field turns can be kept down to a small number. It was also hoped that by the addition of more compensating turns acting directly on the short circuited coils, the short-circuit current would be completely counteracted.

With this winding in view, the field of a General Electric C. E. 5 H. P. was replaced by a laminated field ring with a compensating winding, uniformly distributed, together with the main exciting winding.

The following data was used:

Armature.—Two path winding, four pole motor, 54 3-turn coils, 55 2-turn coils. 109 bars in commutator. Brush covered 2.5 bars on commutator, but was cut down so as to cover but 2

bars. Coil pitch, 14. Connection pitch, 55. Diameter, 9". Width, 4½". 55 slots, .27" wide; .8" deep. 5 H. P. delivered with voltage, 230; and current, 19.5 Amp. R. P. M., 1725.

The main field windings were designed as a regular D. C. winding from formulæ in "Weiner's Dynamo-Electric Machines." An air gap of $^1/_{16}$" was chosen as sufficient. A polar arc of 85% was chosen to increase area of air gap. Thus with a flux density of 44,500 lines per square inch, and a leakage factor of 1.25, the ampere turns per pole were found to be 304. With the field in parallel, as in B. G. Lamme's design for the Westinghouse Company, this gives 63 turns of No. 12 B. & S. per pole.

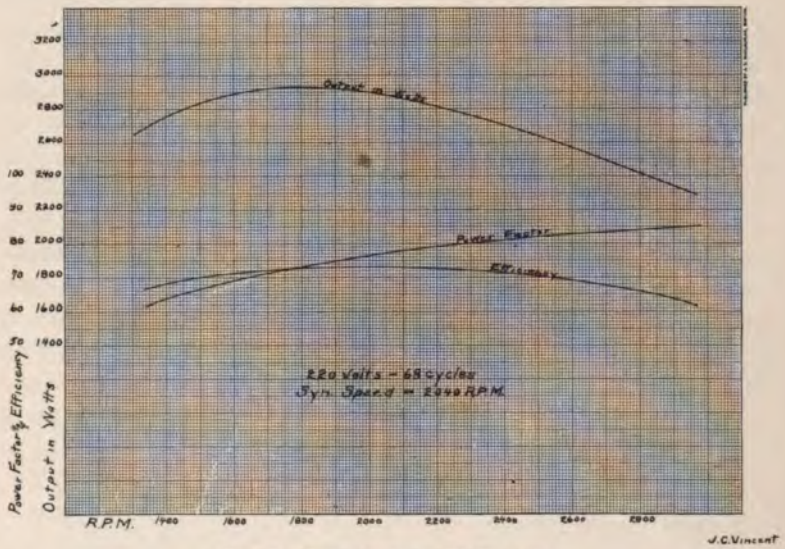


FIG. 4.—OPERATED ON 68 CYCLES.

The compensating winding has the same number of ampere turns as the armature and is equal to 34 turns per pole of No. 6 B. & S. wire (carrying total current) as a distributing winding. This winding was placed in perforated slots at right angles to the main field. Six turns of No. 6 were wound on a small tooth between the main pole pieces, which winding (over-compensating) acts directly on the short-circuited coils in the opposite direction to those coils. The field disks which were made of a special electric steel 0.02" thick, were assembled between brass end plates after having been dipped in special disk varnish and accurately lined up and held in place by 8 thoroughly insulated bolts. From the accompanying cut of the field disk and the view of the winding as completed, an accurate conception of the winding can be formed. The armature was connected in series with the compensating coils, all in series and in turn in series with the four main field coils, which are in parallel.

In testing the motor in its modified form, the input and power factor were obtained by means of a volt-meter, ammeter and watt-meter all calibrated and properly connected. The output was measured by means of a balanced Prony brake acting on a water-cooled pulley. The length of lever arm was 28.16 inches and thus the output in watts

$$= \frac{\text{R. P. M. x lbs. on scale}}{3} = \frac{\text{N P.}}{3}$$

Tests were made with 220 volts. The actual resistances of windings when warm are as follows:

Main Field	0.0694	ohms.
Compensating Field	0.1495	"
Armature, brushes & leads.....	0.347	"

The results of the D. C. test are given in curves shown in Fig. 3.

The output curve is characteristic of all series motors. Also from this curve, it can be seen that too small a value for the leakage factor has been assumed, the leakage factor on this machine being between 2.0 and 2.25. The effect of high speed, small air gap and the straight slots of the armature are shown on the efficiency curve. This drop of the efficiency curve at high speed is no doubt produced by the eddy currents in the pole faces because of the straight slots. If perforated slots were used instead, this fault, no doubt, could be remedied. The most noticeable feature of operation of the motor was its absolutely sparkless operation. A load of 45 amp. (125% overload) was put on for a few seconds and not a spark was seen. This proves its ability as a D. C. motor beyond a doubt.

The result of the 68 cycle 220 V A. C. test are given in curves shown in Fig. 4.

The characteristic rising power factor is seen. The efficiency curve is low, but is to be expected at the comparatively high frequency of the alternating current used. The limitation of output due to the self-induction of the field is shown in the upper curve. As will be noticed, the motor was not run over 1.5 times synchronous speed, at which speed a power factor of approximately 85.5% was reached.

The results of the 30 cycle 220V A. C. test are given in curves shown in Fig. 5.

The sparking at 30 cycles was much less than at 68 cycles, being hardly noticeable at the higher speeds, but increasing as the speed decreased. The test could have been run to lower speeds,

had the current capacity of the armature been greater. Reference to curves on the next page plotted from the above data, show many interesting points. The efficiency curve has been raised 6% and remains more nearly horizontal as the speed increases. The power factor curve has been raised 21 points at the lower speed; i.e., 1400 R. P. M.; at $3^1/_3$ times synchronous speed, the power factor reaches a value of nearly 99%. The output curve shows the desirable quality of approaching that of the D. C. output curves.

On the curve shown in Fig. 6, of relative performance of the motor at cycles varying from 0 to 70 per second, many interesting, instructive and important points are seen. These curves were plotted from the data of the D. C. 30 cycle and 68 cycle tests.

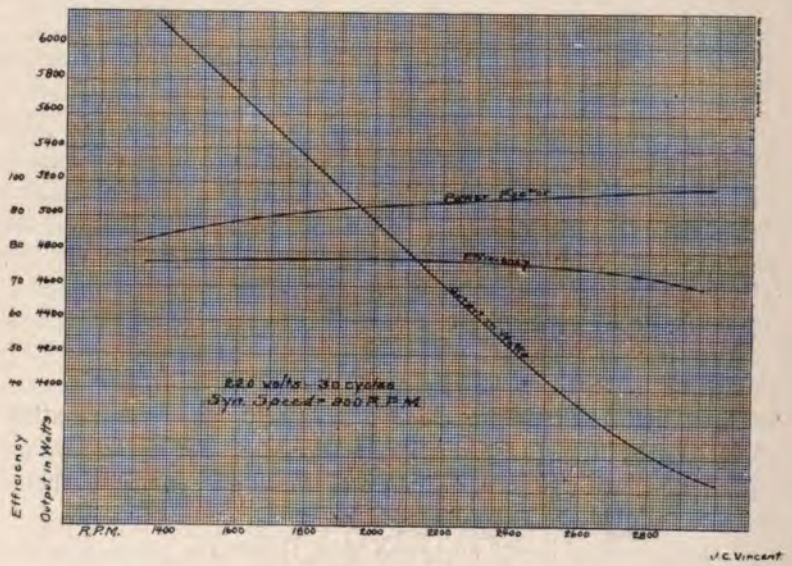


FIG. 5.—OPERATED ON 30 CYCLES.

The upper left hand curves show the relation of the speed, cycles, and the power factor. At $16^2/_3$ cycles per second (the frequency chosen by B. G. Lamme) the power factors at speed between 1400 and 2800 R. P. M., range between 91.5 and 99.+ which power factors, as far as the writer has been able to find, have not been reached by any other series A. C. Motor. The upper right hand curves show the relation of the efficiency cycles and speed. The efficiency of $16^2/_3$ cycles ranges between 75 and 80% which is not at all bad for a small machine. The curves in the lower left hand corner show the very important relation between the cycles and the output. This is especially important at low speeds. Thus at 68 cycles but little power is exerted to produce acceleration, while with decreasing cycles, the power exerted rapidly approaches that of a D. C. series motor. Thus a motor designed similar to the one

tested and used on an electric car would exert but little starting and accelerating force at 68 cycles, while at $16^2/_3$ cycles, the result would be nearly the same as if D. C. were used. The frequency of $16^2/_3$ cycles as chosen, seems to be a wise one since a series A.C. motor at that frequency would have all the characteristics of a D. C. series motor and the current could be used for car lighting by using a special lamp. Thus the advantages of an A. C. high voltage transmission, together with the advantages of a D. C. series motor are combined by the use of a series A. C. motor.

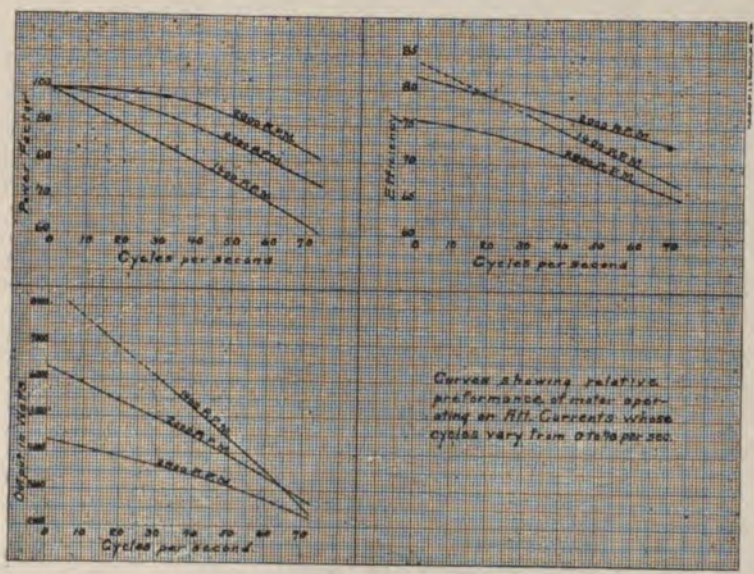

Power Factor
Cycles per second
Efficiency
Cycles per second
Output in Watts
Cycles per second
Curves showing relative performance of motor operating on Alt. Currents whose cycles vary from 0 to 70 per sec.
J. C. Vincent

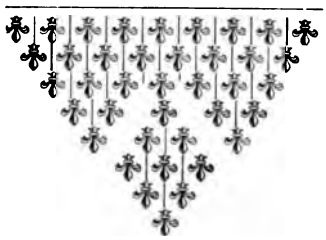
FIG. 6.—RELATIVE PERFORMANCE.

The writer is highly pleased with the results obtained and thinks that if the armature was symmetrical, not two path, and if the slots were perforated, the above results could be bettered in regard to efficiency, power factor and output. An interesting experiment was performed, that of finding the phase relation in the different parts of the winding. The armature was found to produce a lag; the compensating winding, a lead very nearly equal to the lag in the armature, and the main field, a lag.

This lead is produced in the compensating winding because of the fact that the cross flux set up by the armature is stronger than the flux set up by the compensating coils, hence the flux (difference between armature cross flux and compensating flux) passes through the compensating coil in the opposite direction to that in which it would pass in obedience to the current flowing through the coils.

If the compensating flux were stronger than the armature cross flux the lead would be found around the armature while the lag would appear around the compensating coil and would be equal to the lead in the armature.

Another interesting experiment was made—that of using the compensating winding; i.e., a distributed winding for the main field winding. With this distributed winding as main field, sparking at the brushes was reduced to a negligible amount—thus if a motor was designed with a compensating winding to produce a lead sufficient to compensate for the armature and main field at ordinary running speed, or perhaps a little lower, and the main field was made a distributed winding and due regard to the points of design mentioned previously, were made, the writer thinks that a non-sparking, high power factor, simple series A. C. motor would result; one whose power factor would be higher (even unity at the proper speed) than any yet built, and one which would require no German silver leads or equivalent to its armature to check the short-circuit current and lessen the efficiency.



SOME NOTES ON ROPE DRIVING

By John Joseph Flather, Ph. B.; M. M. E.

Professor of Mechanical Engineering, University of Minnesota

Although toothed gearing and belts are the most familiar mediums for the transmission of power in mills and factories, systems of rope transmission for this purpose have been in use for many years; but it is only within the last ten years that they have given promise of being generally recognized in this country as a convenient and efficient means of accomplishing the ends for which they were designed.

The use of hemp rope for power transmission had been revived about 1860 by the Messrs. Combe & Barbour of Belfast, who introduced it successfully into small mills in the north of Ireland. This was followed by its speedy adoption in the jute mills of Dundee, and subsequently in the cotton-mills of England.

Previous to this fibrous ropes had been in use for transmission purposes, but their application had been limited. The use of ropes, however, was not common, and it has only been in recent years that rope-driving has come into prominence as a factor in power transmission.

As the conditions under which the systems were installed have been so varied, it is not surprising to find many cases where the ropes have been rapidly worn out, and replaced by leather belting or other methods of transmission; but where rope-driving has been tried and has failed, investigation will invariably show the absence of suitable conditions or a disregard of correct principles of design or construction. In many applications too great a strain is put upon the rope, and the stretch and wear are rapid; in addition to this, the pulleys are often of unsuitable size, and the rope is unnecessarily weakened through the action of the fibres upon one another. Both of these causes are a constant source of annoyance in a rope-drive which has been poorly designed or constructed. A case in point can be shown where a rope would stretch to such an extent that it had to be taken up every few days when new, and later every two or three weeks—a rope under these conditions lasting less than four months. Investigation showed that a tension-weight of 600 pounds had been placed upon the rope, which was of ¾-inch diameter. A weight of 50 pounds was substituted,

and the rope has been running satisfactorily for three years, and has only been taken up once in that time.

Cases where ropes have suddenly broken are few in number, the risk in this respect being reduced to a minimum by the fact that any defect in a rope, arising either from wear or other cause, will show itself long before the point of danger is reached.

The ropes by which the power is transmitted consist of an elastic substance, and their lightness, elasticity, and comparative slackness between the pulleys are highly conducive to their taking up any irregularity that may occur in the motive power.

Their quiet working and convenience in application, much more so than wide belts, are also features which cause ropes to be looked upon with great favor. Another reason for its rapid progress is the use of the multiple rope, now known as the English system, in which a number of single ropes are spliced and run side by side.

The entire freedom from any risk of a breakdown or stoppage of the works which might occur with gearing was an important factor in replacing the latter by the newer system; the working stress in the ropes being but a fraction of their breaking strength, any signs of weakness in an individual rope would allow it to be removed, and the engine run with the remaining ropes until a convenient opportunity offered for the replacement of the weak member.

Where ropes have been used to replace gearing in the English mills, the plan adopted has been to put in a new, grooved fly-wheel or to place grooved segments upon the existing fly-wheel, when the speed could be increased sufficiently to allow a limited number of ropes being employed, and the width of the wheel-pit was also sufficient for the purpose; but if this plan could not be adopted, grooved pulleys were put on the intermediate shaft, and the ropes carried to the different stories of the mill. It has sometimes been necessary to put in a countershaft, so as to gain speed and obtain a sufficient distance between the centers of the shafts on which the pulleys are placed.

Where rope-driving has been installed in new factories, special provision has been made for the ropes, and we find, in such cases, rope-wells or chambers built in, suitably fitted with platforms and staircases to give access to pulleys and bearings on the various shafts, as shown in Fig. 1.

In such cases the multiple-rope system is used, each wind consisting of a separate rope stretched around the fly-wheel and its individual shaft-pulley, then spliced. The degree of tightness will depend upon the material of the rope and the amount of tension in the slack part necessary for adhesion. In the majority of cases the initial tension is very small com-

pared with the strength of the rope, especially so where the horizontal distance between driving and driven pulleys is great, as, under such conditions, the tension in the slack side due to the weight of rope in the hanging catenary is often sufficient to prevent slipping; a slack upper rope in horizontal or inclined

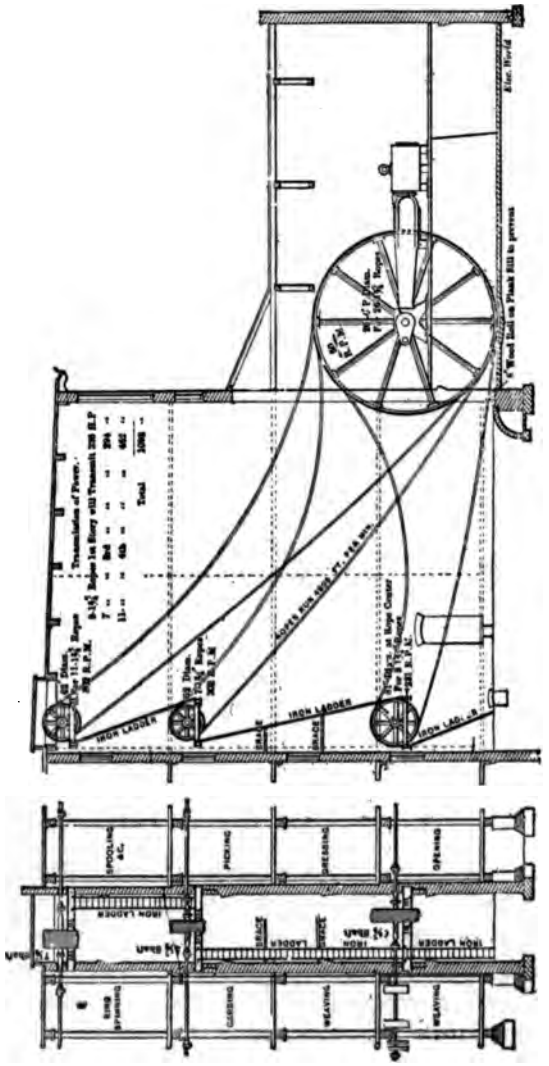


FIG. 1.—METHOD OF DISTRIBUTING POWER TO SEVERAL FLOORS. MULTIPLE ROPE OR ENGLISH SYSTEM.

drives will also increase the arc of contact, thereby increasing the grip of the rope.

As distinguished from the multiple-rope system, the continuous wound rope forms a separate system, in which the necessary adhesion is obtained by a tension-carriage. In this system one rope is wrapped continuously around the pulleys back and forth, and is led over a weighted tightener by means

of suitable deflecting pulleys. An example of this system of rope transmission, in which both vertical and horizontal tension-carriages are employed, is shown in Fig. 2.

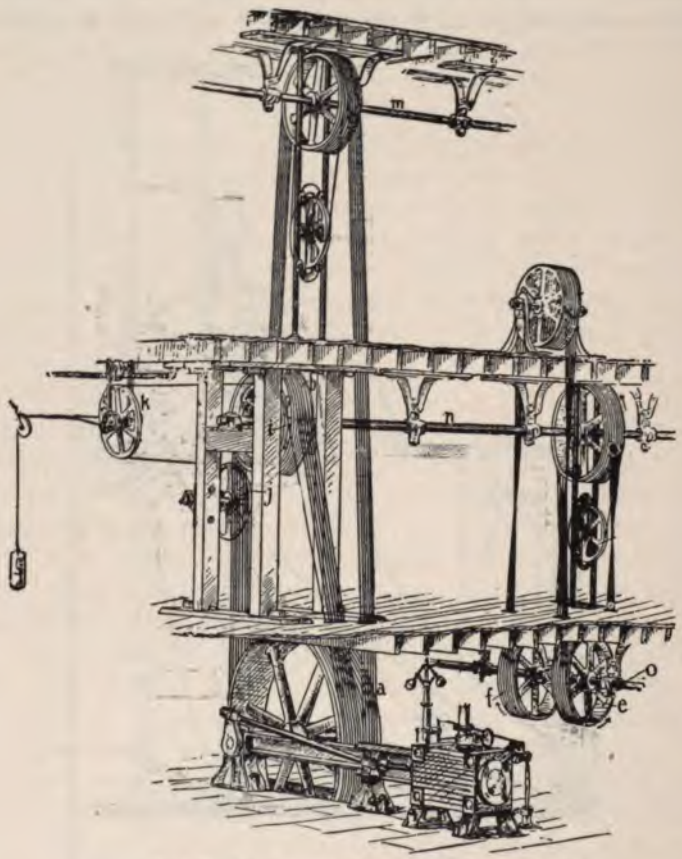


FIG. 2.—TRANSMISSION AT RIGHT ANGLES.

The plant is designed to transmit 250 horse-power from a 14-foot fly-wheel, *a*, which is grooved for twelve 1-inch ropes. The line-shafts, *m* and *n*, are driven independently, and each drive has its own tension carriage. The rope-sheave, *b*, is 72 inches in diameter, and is grooved for five ropes. At the side of the 72-inch sheave is a single-grooved idler, *i*, loose on the shaft, which serves as a guide for the rope to the tension-carriage.

In this case the rope runs continuously around the fly-wheel and sheave from groove to groove. As it leaves the fly-wheel at the left hand it passes over the idler, *i*, to the tension-carriage sheave, *k*, which is suspended on adjustable hangers from a single-pipe track. This sheave is tilted by means of the adjustable hangers, so that the top is in line with the center of the groove of the idler, and the bottom is in line with the center of the

groove of the guide-sheave, *j*, which serves to carry the rope back to the right-hand groove of the fly-wheel.

The employment of multiple idlers is also shown in this figure, where power is transmitted from the shaft, *n*, to another, *o*, at right angles to the first. By engaging one or the other of the driven pulleys, *e* or f, by means of a clutch, the shaft, *o*, may be driven in either direction.

If T_1=tension in tight side of rope,

T_2=tension in slack side of rope,

T_3=slack side tension minus centrifugal force, then it can be shown that

$$T_3 = \frac{T_1}{2.46};$$

that is, the initial tension in the rope, necessary for adhesion, depends upon the tension in the tight side of the rope, and if this be taken equal to $200d^2$ pounds, the back tension may be readily calculated from the above formula, which applies to average work.

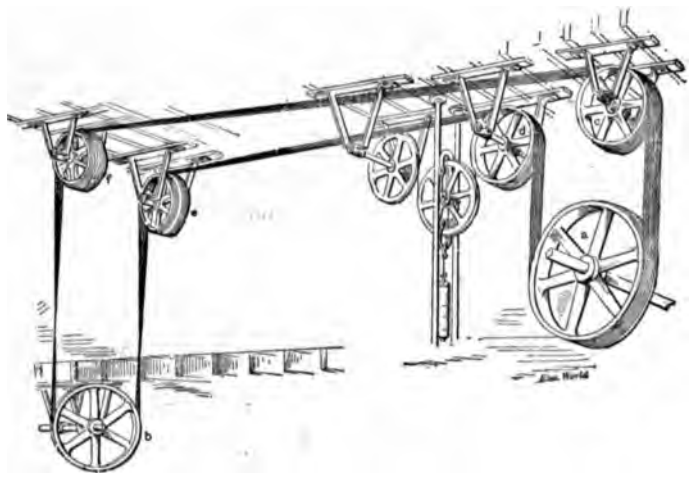


FIG. 3.—ROPE DRIVE WITH SHAFTS AT AN ANGLE AND AT DIFFERENT HEIGHTS.

When diameter of rope equals

⅝	inch	the	initial	tension	=	31	pounds.
¾	"	"	"	"	=	45	"
⅞	"	"	"	"	=	62	"
1	"	"	"	"	=	82	"
1¼	"	"	"	"	=	127	"
1½	"	"	"	"	=	184	"
1¾	"	"	"	"	=	250	"
2	"	"	"	"	=	325	"

The actual weight to be placed on the tension-pulley will depend upon the arrangement of drive, and, in order to obtain the best results, should be determined for each particular case. It is to be noted that with a vertical tension-carriage the weight

of carriage and sheave must be considered as a portion of the weight producing tension in the rope. As previously noted, it is desirable in all cases of rope transmission to so arrange the drive that the slack side of the rope shall be on the upper part of the pulley, thus increasing the arc of contact, as the two sides will then approach each other when in motion.

In order that the desired tensions, T_1 and T_2, shall be attained in the two parts of a rope, the deflections, or sag must be of predetermined values.

Practically, it will be impossible to maintain a constant tension in the rope, so that the amount of sag obtained by calculation is liable to vary with the conditions of service. The following simple method for obtaining the sag is sufficiently accurate for any practical case that may arise, for it must be borne in mind that any theoretical calculation for the deflection of a running rope can at best be only an approximation, as it is exact only when the rope is running at its normal speed, transmitting its full load, and strained to its normal tension.

Let l be the distance between two shafts which are at the same level, and let h be the deflection of the rope corresponding to the tension, T. Then, if we assume the length of rope to be equal to the distance between the shafts, we shall have, approximately,

$$T = \frac{wl^2}{8h};$$

hence the sag of the rope at the center will be

$$h = \frac{wl^2}{8T}.$$

in which $w = 0.32d^2$.

From this formula the following table has been computed:

TABLE I.—DEFLECTION OF ROPE.

Calculated from $h = \frac{wl^2}{8T}$.

Distance between Pulleys in Feet.	Deflection in Feet in Slack Side of Rope when $T_2 = T_1 - P =$				Deflection in Tight Side of Rope when $T_1 = 200d^2$ Pounds.	Deflection in Both Sides of the Rope when Initial Tension $T_0 = 141d^2$
	$86d^2$	$91d^2$	$100d^2$	$112d^2$		
	Corresponding to Velocity in Feet per Minute of:					
	2,000	3,000	4,000	5,000		
30	0.42	0.39	0.36	0.32	0.18	0.25
40	0.74	0.70	0.64	0.57	0.32	0.45
60	1.67	1.58	1.44	1.28	0.72	1.02
80	2.97	2.81	2.56	2.28	1.28	1.82
100	4.65	4.40	4.00	3.57	2.00	2.84
120	6.70	6.33	5.76	5.14	2.88	4.10
140	9.12	8.61	7.84	7.00	3.82	5.58
160	11.90	11.25	10 24	9.14	5.12	7.27

Rope-driving may properly be placed under two heads, according to the nature of the material composing the ropes, whether metallic or non-metallic. With few exceptions metallic or wire ropes are used almost exclusively on long-distance or telodynamic transmission while non-metallic ropes are employed for intermediate and comparative short drives.

Among the materials employed in this method of power transmission, we find special forms of leather belting used as ropes working in V grooves; fibrous ropes, including flax, hemp, cotton, and manilla, are, however, chiefly employed.

In England, manilla is now being used very largely, but cotton ropes were formerly preferred, to the exclusion of all others, for all kinds of driving; but the most probable cause of this was not that cotton was the best or most economical material for the purpose, but that rope-driving is most common at cotton factories, and cotton ropes were made in the locality by men who were familiar with the local product, and had been for years making spindle and rim bands of small size.

In the mills of Dundee and vicinity, and in the north of Ireland, where flax and hemp are worked, we find ropes of hemp, a local product, used entirely.

In many cases ropes of cotton are to be preferred, as they are generally softer and more pliable than the ordinary manilla ropes, thus allowing smaller pulleys to be used with less injury to the fibers.

The cotton fiber is particularly well adapted to the work of being twisted into yarns; the presence of the natural convolutions and comparative smoothness of the surface of the unit filament permit considerable elongation, and the wax on its surface serves as a natural lubricant and prevents the fibers from becoming brittle.

Thus it will be seen that ropes made from fibres possessing these characteristics are particularly well adapted to the transmission of power in which the rope is constantly undergoing a varying strain and is subjected to much flexion.

The strength of cotton ropes is, however, relatively small and, although the weight is about one-fifth less than manilla, for equal diameters, the actual first cost is from fifty to seventy-five percent greater.

Nystrom gives the breaking strength of three-strand cotton rope at less than one-tenth that of similar manilla rope, but this is apparently too low for a good quality of transmission rope.

Tests made at Watertown on a number of Lambeth ropes varying in size from 1 inch to $2\frac{1}{8}$ inches in diameter indicate that the breaking strength is equal to about $4000d^2$ pounds, as shown in the annexed table, while the extension varies from

twenty to twenty-five per cent, corresponding to a reduction in diameter of about fifteen per cent.

The weight of these ropes is very closely $0.26d^2$ pounds per foot of length.

TABLE II.—STRENGTH OF LAMBETH COTTON TRANSMISSION-ROPES.

Diameter of Rope in Inches d.	Ultimate Breaking Strength $S=4000d^2$.
½	1,000
⅝	1,550
¾	2,200
⅞	3,000
1	4,000
1¼	6,200
1½	9,000
1¾	12,200
2	16,000

On account of its peculiar construction the Lambeth cotton rope is well adapted to transmission purposes. It is made of four strands twisted together in the usual manner, but the strands are themselves composed of a bundle of fine yarns and have scarcely an appreciable twist. Each bundle, comprising many hundred yarns, is wound spirally with smaller bundles of about 100 yarns each.

In this way the outside of the rope acts as a shield or covering to the cores which do the work. By this means a certain amount of the natural elasticity of the cotton is retained, and its pliability is much greater than in ordinary regular-laid ropes.

As we have already noted, manilla rope is used very extensively for transmission purpose, but its application has not always met with that success which would follow a more thorough knowledge of its requirements. Inefficient rope-drives are erected and run for a few months, or perhaps only days, and are replaced with larger ropes if the sheaves will permit, or, as in many cases, the ropes give way to leather belting, and henceforth rope-driving is condemned. The true cause is not so much the inefficiency of the ropes as it is the lack of knowledge governing their use and application. Manilla, or more properly, manilla hemp (abaca) rope, is made from the fibers of the *Musa textilis,* a plant closely allied to the banana, growing near Manilla. The fibers are a part of the outer covering of the leaf-stalk, which attains a length sometimes as great as fifteen feet. To obtain fibers of suitable size for manufacturing rope the leaf-stalks are sub-divided, and in the process of segregation the fiber assumes an appearance somewhat similar to that produced in splitting a piece of wood—it is rough, and uneven, and more or less splintery throughout its length. These fibers have great strength in the direction of their length, but are weak trans-

versely;* when made into rope they are compelled, in bending over the sheave, to slide on each other while under pressure from the load. This causes the internal chafing and grinding which, if not prevented, soon wears out a rope when subjected to bending strain.

In addition to the action of the fibers upon each other, the strands and the yarns of which the strands are composed also slide a small distance upon each other, causing friction, and hence internal wear.

Aside from the external wear which a rope suffers from contact with its sheave (part of which is the differential driving effect), these two are the principal causes of rapid wear in a rope-drive, to remedy which we must in the first case lubricate the fibers, and in the second prevent undue flexure of the rope by using large pulleys and avoiding unnecessary bends.

Lubrication of ropes is provided for in various ways. Frequently the rope is laid up dry, and a coating or dressing is given to the exterior, which is supposed to penetrate to the interior and lubricate the fibers. With some dressings this may occur, but with others the effect is merely local; the interior of the rope remains dry, and much bending soon wears it out. With cotton ropes, as we have already noted, the internal chafing and wear is very much reduced, and for this reason cotton ropes are laid up dry and are not usually lubricated; they are, however, generally coated with some form of dressing to prevent the fiber from rising or the rope fraying, and to protect it from an undue amount of moisture when exposed to the weather; it also assists in retaining the natural moisture in the fibers, without which they would become brittle and weak.

According to the nature of the dressing, the interior may or may not be affected by the outer coating. When exposed to wet or dampness cotton does not wear as well as manilla, and for outdoors drives or such special cases, where the ropes are subjected to much moisture, as in paper mills, water-wheel pits, or similar locations, manilla is to be preferred.

A manilla rope with fibers properly lubricated will, under the same conditions, outlast from two to four similar dry-laid ropes which are allowed to run dry. Manilla transmission-ropes are generally laid up in tallow, paraffine, soapstone, pine-tar, or some mixture composed of tallow, resin, graphite, beeswax, and other materials arranged in various proportions.

A rope made in this manner will give excellent results if properly erected, and will last from three to eight years, depending upon the conditions of service.

* The tensile strength of manilla fibers will average over 30,000 pounds per square inch of section.

An inspection and tabulation of the results of numerous tests on manilla rope, from Table III has been computed, shows that the strength per square inch increases as the diameter of the rope decreases. Formulas for the strength of rope based upon the circumference and a constant multiplier—as, for instance, $S = 800c^2$, where S is the breaking strength and c the circumference—must be regarded as giving only an average value for diameters approximating those experimented upon.

TABLE III.—STRENGTH OF MANILLA TRANSMISSION-ROPES.

Dia. of Rope = d.	Breaking Strength.	Strength per sq. in.
½	1,900	12,200
⅝	2,900	11,950
¾	4,100	11,750
⅞	5,500	11,525
1	7,100	11,350
1⅛	8,800	11,125
1¼	10,900	10,975
1½	15,000	10,625
1¾	19,800	10,300
2	25,100	10,000

The above values are for new manilla ropes made of selected stock; ropes that are greasy or wet will be reduced in strength from 20 to 30 per cent, but when ropes are used for transmission of power the lubrication of the fibers is of more importance than the actual breaking strength of the rope, as in any case the apparent working strain, as calculated from the power transmitted and the speed of the rope, should not be taken greater than 5 per cent of the ultimate strength; in many cases not more than 2 per cent is used.

The working strain in existing rope transmissions will be found to vary considerably, but plants which have been successful, as well as those in which the wear of the rope was destructive, indicative that $200d^2$ pounds (d = diameter of rope) is an economical working strain, and should be considered as the load for the lasting qualities of the rope; in many cases, however, the first cost, the more convenient adaptation of smaller ropes, and the use and lesser cost of smaller pulleys outweigh the greater economy obtained by the larger ropes, and loads are carried far in excess of that given. By the use of a greater number of wraps the working load on each will be reduced; but this adds to the first cost of the plant, and many concerns prefer to put in a new rope every year or two rather than put in more or larger ropes every six or eight years.

The ropes most commonly found in use vary from ⅝ inch to 2 inches in diameter, although other sizes are frequently em-

[* Trans. A. S. M. E., Vol. XII, p. 230.]

ployed; in one case, cited by Mr. T. S. Miller,* a rope no larger than $^5/_{16}$-inch diameter is used very satisfactorily to transmit 20 horse power.

The largest rope in use for this purpose that we know of is 3½ inches in diameter; it is of cotton (Lambeth), and is used to drive the cable drums in the Western Street power station of the West Chicago Street Railway Company.

In main drives, where a number of ropes are used, the tendency, as judged from recent practice, seems to favor a diameter about 1⅝ or 1¾ inches.

We are aware that small ropes are advocated and installed by many engineers, but we believe this to be wrong both in principle and practice. In rope-driving the first cost and erection of small driving-pulleys may influence a designer to use small ropes; but as ropes are sold by the pound, and as the weight necessary to transmit a given power should be the same, irrespective of the diameter, it is evident that the first cost of the rope itself will be the same, whether large or small ropes are employed. Moreover, if the pulley is proportioned to the size of rope in each case, the smaller rope will last only about one-third as long as a rope twice its size, under similar conditions.

If we assume that there is a minimum diameter of pulley which may be safely used for any given diameter and speed of rope, it will be evident that the number of revolutions of the pulley imposes conditions which limit the choice of rope diameter.

Thus, if the maximum speed of rope be taken at 5,000 feet per minute for a permanent installation, in which the working load is $200d^2$ pounds, and the least diameter of pulley,

$$D = d^{1.7}\ (\sqrt[3]{V}) + 12''.$$

then the greatest number of revolutions which can be obtained under these conditions with a 1-inch manilla rope will be 550.

If the least diameter of pulley for cotton ropes be taken equal to $0.8D$, then the greatest speed will be approximately 700 revolutions per minute for the same diameter of rope. If a greater rotative speed is desired, it is evident that a smaller rope must be used.

The construction of rope pulleys is a matter of considerable importance, for it is evident that the size, shape and condition of the pulley all exert a marked influence upon the efficiency of rope transmission. The size of the pulley materially affects the wear of the rope, as the larger the sheaves the less the fibers of the rope are flexed, and the less they slide on each other; consequently, there is less internal wear of the rope.

* Trans. A. S. M. E., 1891.

The minimum diameter of the pulley, as given by different authorities, varies from thirty to forty times the diameter of rope to be used. Forty times the diameter of rope for manilla is excellent practice, and experience has shown that a larger multiplier would be still better, as the larger a pulley the better for either belt or rope passing over it; but such a rule, although convenient to use, was evidently founded upon large-sized ropes running at a high velocity. From an investigation of numerous examples of pulleys in operation under varying conditions, some of which work satisfactorily and other very poorly, the following empirical formula has been determined, and is believed to represent the requirements of good practice for least diameter of pulley:

$$D = d^{1.7} \times \sqrt[3]{V} + 12'',$$

in which D = pitch diameter of pulley in inches;
d = diameter of rope in inches;
V = velocity of rope in feet per minute.

Table IV gives values of D for ropes varying from ¾-inch to 2 inches in diameter, running at 2,000 to 5,000 feet per minute.

TABLE IV.—LEAST DIAMETER OF PULLEY FOR GIVEN DIAMETER AND SPEED OF MANILLA ROPE.

$$D = (d^{1.7}) \times \sqrt[3]{V} + 12''.$$

Diameter of Rope.	Velocity of Rope in Feet per Minute.			
	2,000	3,000	4,000	5,000
¾	20	21	22	22½
1	25½	26½	28	29
1¼	30½	33	35	37
1½	37	40½	43½	46
1¾	44	49	53½	56½
2	53	58½	63½	67

It is well to remember that the cause of many failures and much trouble experienced in rope-driving is due to the use of too small a pulley for the size of rope and tension carried; but we have yet to hear of a case where the diameter of pulley has been too great. When it is not absolutely necessary to restrict the diameter to the smallest possible which may be used, the least diameter should conform to that given in Table V, which has been arranged for general work, and gives least diameters, to the nearest half foot, for rope-pulleys suitable for all speeds within the limits of good practice.

TABLE V.—ROPE PULLEYS FOR GENERAL WORK.

Diameter of Rope . . .	¾	1	1¼	1½	1¾	2
Diameter of Pulley . . .	24	36	48	60	72	84

It is evident, also, that the condition and shape of the groove is a matter of much importance; so generally is this recognized that manufacturers now almost universally turn their rims to special gauges and templets, which insure uniformity in diameter and shape of groove. Formerly the bottom of the groove was furnished with spikes, or the sides were cut into angular teeth, in order to prevent the rope from slipping; but a greater experience with rope-driving has shown that the whole surface of the groove must be perfectly smooth, and should be carefully polished as well as machined, since the fibers of the rope, if allowed to rub on a rough-turned or cast surface, will gradually break, and thus give the rope a short life. It is also necessary to avoid using any pulley with sand or blow-holes in the groove, as they are very destructive to a rope; when blow-holes occur if not honeycombed excessively, they should be filled in with lead, or, preferably, Babbitt's metal; otherwise the pulley should not be used.

When only a small amount of power is to be transmitted, the rope rests upon the bottom of the groove, which is the case also when the pulley merely acts as an idler; but in most cases the rope rests against the sides of the groove, and is wedged between them, so that the frictional resistance to slipping is increased.

The sides of the groove vary ordinarily from 30° to 60°—the best angle to use in any given case will depend upon the tension in the rope and upon its condition. A mean angle of 45° is used by a number of engineers, although, when ropes are lubricated with tallow, lard, or other grease, a smaller angle may be employed in order to increase the friction, as the greasy rope is apt to slip. On the other hand, a heavy stress and a dry rope will cause the latter to be wedged tightly into a narrow groove, thus producing undue wear and causing a loss of power in transmission. In most cases an angle of 45° will be found to give very satisfactory results.

In determining the horse-power which a rope will transmit, under given conditions, the centrifugal force due to the velocity and weight of rope is an important factor, and its influence should be considered in all cases where the speed is greater than 2,000 feet per minute; for, at high velocities, this force diminishes the pressure exerted between the rope and the circumference of the pulley, thus reducing the friction between rope and pulley. When, therefore, a rope has to transmit a given force, P, it must be subjected to a greater tension the greater the centrifugal force, F_0. At a speed of about 90 feet per second the centrifugal force increases faster than the power from increased velocity of the rope, and at 140 feet per second this

force equals the assumed allowable back tension in the rope; and since the transmitting force is equal to the difference in tension in the two parts of the rope, it will be seen that no power will be transmitted at this speed unless the assumed allowable tension be exceeded.

It is evident that for a given total tension the less back tension required to prevent the slip of the rope on the pulley the greater will be the power transmitted at a given speed. If the arc of contact on smaller pulley, the coefficient of friction between rope and sheave, and the total tension in the rope be known, the tension on slack side of the pulley, and hence the horse-power transmitted, can be readily determined from the following considerations:

Assuming, as before, that the driving force, P, is equal to the difference in tension, T_1, on the driving side of the rope and T_2 on the driven side, and noting that the driving force must equal the friction, F, between the surfaces, we obtain

$$T_1 - T_2 = P = F.$$

The friction, F, depends upon the arc of contact α, between the rope and its sheave, the coefficient of friction, φ, and upon the centrifugal force, F_0, set up in the rope, due to its velocity and weight; it is, however, independent of the diameter of pulley. To determine the values of F, T_1 and T_2 it will be necessary to assume a given tension in the rope, also its speed and weight, coefficient of friction, and arc of contact.

Let f = friction between element of rope and pulley;
g = acceleration due to gravity = 32.16;
t = allowable working tension = $200d^2$ pounds;
v = velocity of rope in feet per second;
w = weight of rope per unit length and area;
z = abbreviation for $\frac{w}{g}\frac{v^2}{t}$;
F_0 = centrifugal force due to speed and weight of rope;
P = driving force = $T_1 - T_2$;
T_1 = tension in rope on tight side = $200d^2$ pounds;
T_2 = tension in rope on slack side;
α = least arc of contact between rope and pulley—in circular measure = 0.0175.
φ = coefficient of friction;
ϵ = base of the hyp. log. = 2.7183.
θ = angle of groove in pulley.

The weight, w, per foot of length varies considerably in different makes of rope, depending upon the amount of twist and the foreign matters in the rope.

It is well known that much of the cheaper rope on the market is largely adulterated with weighting material, such as gelatine size, French clay, and white lead. Thus some manilla ropes will weigh not more than $0.26d^2$ pounds when dry and very loosely twisted; in other cases the weight will be as much as $0.46d^2$ pounds per foot of length. The value we have given, viz.: $0.32d^2$ pounds corresponds very closely to the average weight of good quality lubricated transmission ropes.

Cotton ropes are about 20 per cent lighter for equal diameters, and will vary from $0.20d^2$ to $0.29d^2$ pound per foot. In the following table VI, $0.32d^2$ has been used for manilla, and $0.26d^2$ for cotton ropes.

TABLE VI.—WEIGHT OF ROPES.

Diameter of Rope	Weight in Pounds per Foot.	
	Manilla. $w = 0.32d^2$	Cotton. $w = 0.26d^2$
¾	0.18	0.15
1	.32	.26
1¼	.50	.40
1½	.72	.58
1¾	.98	.79
2	1.28	1.04

As the weight of a manilla rope one foot long $= 0.32d^2$ pounds, the value of z for varying speeds can be determined from

$$z = \frac{wv^2}{gt} = \frac{0.01\, d^2 v^2}{t}.$$

If now we assume a constant working stress $t = 200d^2$ pounds, then

$$z = \frac{0.01\, d^2 v^2}{200d^2} = 0.000005v^2.$$

In the work which follows we shall assume that the tension, T_1, in the rope on the tight side (driving tension) equals the allowable tension, t.

From these assumptions the following table (VII) of the values of $1-z$ has been computed:

TABLE VII.—VALUES OF $1-z$ FOR A WORKING STRESS EQUIVALENT TO $200d^2$ POUNDS.

Velocity in Feet per minute.	Values of $1-z$.	Velocity in Feet per Minute.	Values of $1-z$.
1,000	0.98	5,500	0.58
2,000	0.94	6,000	0.50
2,500	0.91	6,500	0.41
3,000	0.87	7,000	0.32
3,500	0.83	7,500	0.22
4,000	0.78	8,000	0.11
4,500	0.72	8,500	0.0
5,000	0.65		

Now it can be shown* that

$$\frac{T_1}{T_2} = \varepsilon \varphi \alpha (1 - z).$$

or the common logarithm of

$$\frac{T_1}{T_2} = 0.4343 \varphi \alpha (1 - z).$$

It will be seen from the above that when the velocity of the rope is as great as 8,500 feet per minute, $1-z = 0$, hence

$$\frac{T_1}{T_2} = 1; \text{ that is, } T_1 - T_2 = 0,$$

and therefore no power will be transmitted unless the assumed working tension be exceeded.

In average work the lesser arc of contact embraced by the rope—generally on the smaller pulley—will be about 165°, and this value may be assumed for approximate calculations with a working degree of accuracy. If the angle in degrees is known, its value α, in circular measure, can be obtained from Table VIII in which $\alpha = 0.0175\, \alpha°$.

TABLE VIII.—ANGLE EMBRACED BY ROPE.

Degrees, $\alpha°$	Circular Measure, α	Fraction of Circumference, $360'\alpha°$
105	1.83	0.29
120	2.09	0.33
135	2.35	0 37
150	2.62	0.42
165	2.88	0.46
180	3.14	0.50
195	3.43	0.54
210	3.66	0.58
240	4.19	0.66

* See the author's Treatise on Rope Driving, pp. 114 et seq.

If we now assume the coefficient of friction, φ, to be 0.31 for a 45° groove, we may obtain the value of the ratio of tensions,

$$\frac{T_1}{T_2},$$

and knowing the value of T_1, namely $200d^2$ pounds, the horse-power transmitted may be readily determined from

$$H.P. = \frac{(T_1 - T_2)V}{33{,}000}.$$

In order to simplify calculation, the following table (IX) contains value of

$$\frac{T_1}{T_2} \text{ and } \frac{T_1}{P},$$

which will enable the horse-power transmitted by a rope to be determined with a degree of accuracy depending upon the assumption of the coefficient of friction, which in general may be taken equal to

$$\varphi = 0.12 \operatorname{cosec} \frac{\theta}{2},$$

in which θ equals groove angle in pulley.

TABLE IX.—FRICTION AND STRESS MODULI.

$\varphi\alpha(1-\varepsilon)$	$\frac{T_1}{T_2}$	$\frac{T_1}{P}$
0.1	1.11	10.41
0.2	1.23	5.40
0.3	1.35	3.86
0.4	1.49	3.02
0.5	1.65	2 54
0.6	1.82	2.22
0.7	2.01	1.99
0.8	2 22	1.82
0.9	2.46	1.69
1.0	2.72	1.58
1.1	3.00	1.50
1.2	3 32	1 43
1.3	3.67	1.37
1.4	4.06	1.33
1.5	4.48	1.29

The following application will show the use of the tables: Let it be required to determine the horse-power transmitted by a rope 1 inch in diameter, running at a velocity of 4,000 feet

per minute over a pulley with 45° grooves. Assuming an arc of contact of 165°, we find from Table VII $a = 2.88$; for the required velocity, 4,000 feet per minute, Table VI gives 0.78 as the value of $1 - s$; therefore, assuming the coefficient of friction $\varphi = .31$, we obtain

$$\varphi a (1 - s) = 0.31 \times 2.88 \times .78 = .69.$$

From Table IX the value of $\frac{T_1}{P}$ corresponding to 0.69, is about 1.99; and as $T_1 = 200d^2$ pounds $= 200$ in the present case, we find $P = \frac{T_1}{1.99} = 100$ pounds. Since $\frac{PV}{33000} =$ h. p., there is obtained h. p., $= \frac{100 \times 4000}{33000} = 12.15$.

For any special case where the data are known or may be determined, the formulas and tables already given should be used to ascertain the horse-power transmitted, or the diameter and number of ropes required for a certain work, as the case may be. For average work, however, it will be found that the assumed values of * and *, previously noted, will give very satisfactory results, and upon these assumptions the following table of horse-power has been computed for various-sized ropes, running at speeds from 1,000 to 7,500 feet per minute.

TABLE X.—HORSE-POWER TRANSMITTED BY ROPES.

Working Strain $= 200d^2$ pounds.

d = diameter of rope in inches.

Velocity of Rope in Feet Per Minute.	Diameter of Rope.						
	⅝	¾	1	1¼	1½	1¾	2
1,000	1.24	2.25	3.57	5 59	8.02	10.85	14.26
2,000	2.70	3.84	6.84	10.68	15.39	20.93	27.36
2,500	3.30	4.71	8.38	13.10	18.86	25.66	33.54
3,000	3.83	5.46	9.80	15.39	21.87	29.74	38.88
3,500	4.30	6.23	11.09	17.33	24 94	34.03	44.35
4,000	4.74	6.83	12.15	18.98	27.33	37.17	48.59
4,500	5.01	7.24	12.89	20.15	29 00	39.45	51.57
5,000	5.20	7.47	13.29	20.76	29.89	40.65	53.15
5,500	5.29	7.60	13.53	21.14	30.43	41.39	54.11
6,000	5.08	7.32	12.10	20.36	29.32	39.77	52.12
6,500	4.74	6.83	12.13	19.00	27.34	37.21	48.63
7,000	4.12	5.93	10.54	16.47	23.72	32.26	42.18
7,500	3.25	4.67	8.32	13.00	18.73	25.42	33.23

The graphic representation of these values, Fig. 4, shows the effect of centrifugal force in diminishing the power transmitted under an assumed working tension, and would indicate that with tensions of $200d^2$ pounds, the speed should not exceed 5,500 feet per minute.

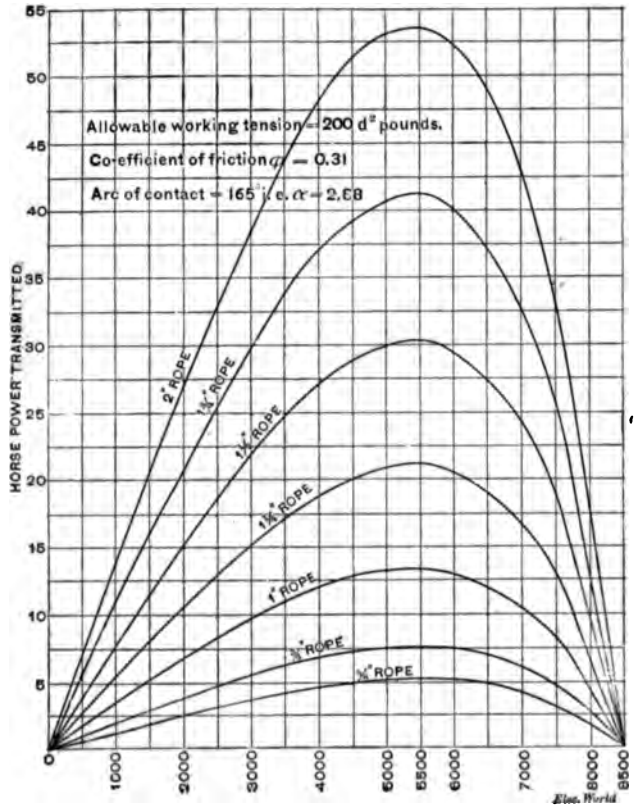


FIG. 4.—HORSE POWER TRANSMITTED BY MANILLA ROPES.

In laying down a rope over its pulleys it is the practice of some engineers to strain both manilla and cotton ropes as much as possible and unite the ends with a temporary short splice when first put over the pulleys; after running a few days a permanent stretch is given to the rope, which is then respliced with a long splice, the strain on the rope being very much reduced in this latter case.

Many engineers favor a short splice for permanent work, in that it is easily made and holds well, and offers a lesser length of enlarged portion for surface contact with the pulley.

If properly made, however, there need be no enlarged portion, and since a long splice is stronger, we find such joints preferred in most cases.

CONSTITUTION OF ENGINEERS' SOCIETY.

The Constitution as printed below was adopted by the Engineers' Society April 22, 1904. While most of the principles of the old Constitution, which it supersedes, have been retained, it embodies several new features. To make it of easy reference for all and to provide an indestructible record it is printed in this book.

Preamble.

We, the undersigned, students of Engineering in the University of Minnesota, in order:—(1) To establish a more perfect union and fellowship; (2) To promote a high standard of character among the students of Engineering; (3) To arrange for the publication of the "Engineers' Year Book; do form ourselves into a society.

Section 1.—Name.

Art. 1. The name of this Society shall be, The Engineers' Society of the University of Minnesota.

Section 2.—Membership.

Art. 1. Membership in this society shall be limited to students, pursuing regular or special work in Engineering, who have been registered students in the University of Minnesota for at least one (1) semester.

Art. 2. An application for membership shall be made, in writing, to the Secretary of the society, who shall present the name of the applicant to the society at the first regular business meeting. At the next regular meeting, the application shall be voted on as provided for in Sect. 5, Art 3. If the ballot contains two (2) negative votes, the application shall be rejected. Further applications for membership shall not be recognized by the Society until after the expiration of three (3) months.

Art. 3. A written ballot, folded, shall be taken. The President shall appoint two (2) tellers, who shall count the ballot and report to the President. After each ballot has been completed the ballot shall be destroyed.

Art. 4. Any man may be elected an honorary member of this society provided election is held at regular business meeting.

Art. 5. Members in good standing on graduation, become honorary members.

Art. 6. An honorary member on payment of society dues, may become an active member.

Art. 7. A member may be expelled from the society, for due cause, by a two-thirds vote of the members voting, as provided in the by laws. The member accused shall not cast a vote.

Section 3.—Officers.

Art. 1. The officers of this society shall be President, Vice-President, Secretary, Treasurer, and Business Manager.

Art. 2. The President, Treasurer and Business Manager, shall have been students for at least three (3) years; and the Vice President and Secretary, students for at least two (2) years; in a College of Engineering.

Art. 3. The duties of President shall be, to preside at the meetings of the society, and to perform such other duties as are further provided for in this Constitution, and as usually devolve upon a president.

Art. 4. The duties of the Vice-President shall be to aid the President in the performance of his duties, and to perform these duties in the absence of the President.

Art. 5. The duties of the Secretary shall be: to keep a record of the proceedings of the meetings of the society, to take charge of the Constitution, By-laws, and such other books and records as the society may have; and to carry on the general correspondence of the society.

Art. 6. The duties of the Treasurer shall be to receive all money paid into the society; and to pay the bills of the society on the presentation of an order signed by the President and Secretary of the society. The Treasurer shall keep a written account of all money received and paid out by him, and shall make a report thereon, at the annual meeting for the election of officers or at any time he shall be called upon to do so by the society.

Art. 7. The duties of the Business Manager of the society shall be to arrange for the disposal of the Year Books, and Exchanges of the society, and to transact such other business as the society may require of him.

Art. 8. There shall be three standing Committees as follows: A Year Book Committee, A Program Committee, and an Auditing Committee.

Art. 9. The Year Book Committee shall consist of Business Manager, Editor in Chief, and department Editors as follows: An Editor and Assistant Editor from the College of Electrical Engineering; an Editor and Assistant Editor from the

Department of Mechanical Engineering; an Editor and Assistant Editor from the College of Civil Engineering.

Art. 10. The Business Manager and Editor-in-chief shall be members of the Senior class. No person shall be a member of the Year Book Committee who shall not have been a student of Engineering in the University of Minnesota for at least two years.

Art 11. The Program Committee shall be appointed by the President and shall consist of three (3) members. The duties of this committee shall be to provide for lectures before the society by alumni, faculty, and others prominent in engineering work.

Art. 12. The Auditing Committee shall consist of three (3) members appointed by the President. The duty of this Committee shall be to inspect the books of the Treasurer, Business Manager of the Society, and Business Manager of the Year Book; and to report on the same at the annual meeting for the election of officers.

Art. 13. The officers of the society and the members of the committees shall hold office throughout the college year for which they are elected or until their successors are elected. The duties of the new officers begin June 1st.

Section 4.—Quorum.

Art. 1. A quorum for the transaction of business shall consist of eleven (11) members in good standing.

Section 5.—Dues.

Art. 1. The dues of this society shall be one (1) dollar per year.

Art. 2. The Secretary shall notify all members who have not paid their dues by the twenty-first (21st) day of September. The names of all members who have not paid their dues on or before the first (1st) day of October shall be dropped from the membership roll.

Section 6.—Meeting.

Art. 1. There shall be an annual meeting for the election of the officers of the society, and the members of the Year Book Committee on the first Friday after the first Tuesday in May.

Art. 2. The annual reports of the various committees and those of the Treasurer and Business Manager shall be received at this meeting.

Art. 3. The President may call a meeting at any time, provided notices are posted three days previous.

Section 7.—Rules.

Art. 1. The rules of order of this society shall be those as set forth in "Roberts' Rules of Order," except when they conflict with the provisions of this constitution. These rules may be suspended by a vote of two-thirds majority.

Section 8.—Amendments.

Art. 1. This constitution can be amended at any meeting of the society by a two-thirds vote of members present, provided the amendment was submitted in writing at the previous meeting.

BY LAWS.

Section I.

Art. 1. The Order of Business in the meetings of this society shall be as follows:—

(1) Roll call.

(2) Reading of minutes of previous meeting and their approval.

(3) Reports of standing committees.

(4) Reports of select committees.

(5) Unfinished business from previous meeting.

(6) New business.

(7) Adjournment.

Section II.

Art 1. Nominating Committee. On or before the fifteenth (15th) day of April, the President shall appoint one senior from each department of engineering, to constitute a nominating committee, for the nomination of officers for the ensuing year.

Section III.

Art. 1. Method of Expulsion of Members.—A written notice shall be given to the President of charges to be made against any member; specifying the nature of the charges, and signed by the person or persons making the charges. The President shall then give due written notice to the person against whom the charges are to be made; at least three days before action is taken by the society.

Art. 2. If a member resigns his membership in the society, before the meeting is called to order, at which charges are to

be brought against him, all written documents referring to the charges are to be destroyed by the President, and no action taken thereon.

Art. 3. Due notice of the resignation of a member shall be given to the society by the Secretary at the next regular meeting, and such resignation shall then stand accepted.

Section IV.

Art. 1. By Laws may be suspended by a four-fifths (4-5) vote of the members present.

Section V.

Art. 1. These By-Laws may be amended by a two-thirds (2-3) vote of the members present, provided the amendment was submitted, in writing to the society at a previous meeting.

The above Constitution was drafted by the following committee:

A. R. Fairchild,
R. E. Stanton,
E. B. Lewis,
W. C. Adams,
E. J. Cheney.

YEAR BOOK

OF

THE ENGINEERS' SOCIETY

1905

ANNOUNCEMENT

The YEAR BOOK is a scientific publication issued by the Engineers' Society, of the College of Engineering and the Mechanic Arts, University of Minnesota.

It is essentially technical in its scope, aiming to present articles contributed by honorary and active members of the Society which will be of interest and value to the practical engineer as well as the student.

This is the thirteenth annual publication of the YEAR BOOK and is, as usual, in charge of an editorial staff selected from the Departments of Civil, Electrical and Mechanical Engineering. The price of the YEAR BOOK is fifty cents. Copies of previous years may be had by addressing

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1905 CLASS OF ENGINEERS, UNIVERSITY OF MINNESOTA

YEAR BOOK

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A MODERN RAILWAY TEST

F. C. CUTTER and H. E. GERRISH

The following is a brief account of a recent series of tests made by the Great Northern Railway Company on the second district of their Montana Division, running between Williston, North Dakota, and Glasgow, Montana. This division was selected on account of its particularly level and straight track which extends over nearly the entire distance of 156 miles.

The objects of the test were (1) to obtain the acceleration at different rates of speed of trains of varying tonnages which ran in the cases mentioned from 1500 to 2300 tons, (2) to determine train resistances, and (3) to determine tractive efforts and drawbar pulls at different loads.

There were in all eighteen tests, twelve being made on freight and six on passenger trains. The engines in use on this district are the Mastodon 4-8-0 type Brooks locomotive for freight work and the ten-wheeler 4-6-0 type Rogers locomotive for passenger work. The tests made were very complete, all engine data being determined as per the instructions given in the Transactions of the American Society of Mechanical Engineers, vol. xiv, page 1312, while a dynamometer car was used for train resistance and other observations.

Six men were used in the tests, one general overseer, one man stationed in the cab, two men stationed out on the front end of the

engine (one over each cylinder) and two men back in the dynamometer car. The principal duty of the front end men was to take indicator cards, which as a rule were obtained every two miles, though special intermediate ones were sometimes taken. A pyrometer and a flue-gas thermometer were placed in the smoke-box to obtain the temperature of the escaping gases, and a throttling calorimeter was fitted onto the steam-pipe entering one of the cylinders to obtain the quality of the steam used. A connection was made between the steam-chest and the indicator on one side of the engine and, by opening a side cock, steam-chest diagrams could

Fig. 1. Reducing Motion

be obtained on the same card as the cylinder diagrams. By means of a push-button and an electric circuit signals were sent from the front end back to the cab and to the dynamometer car, so that readings in the cab could be obtained simultaneously with the taking of a card, and the number of the card noted on the dynamometer roll so as to be able to obtain the draw-

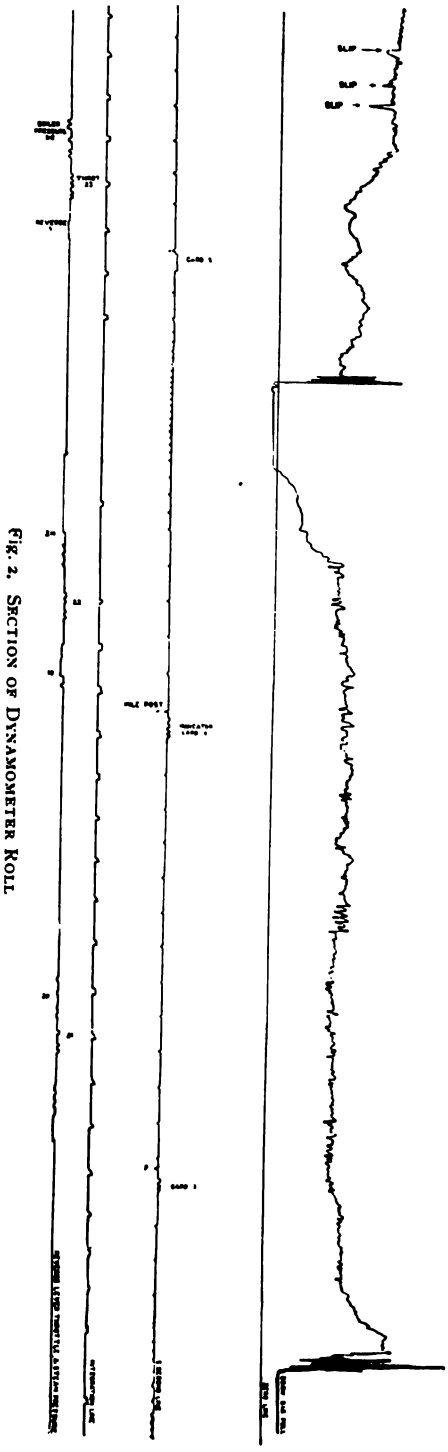


Fig. 2. Section of Dynamometer Roll

bar pull from the dynamometer roll at the same instant.

The duties of the cab man were to take steam pressures, throttle, and reverse-lever positions, simultaneously with the taking of the indicator cards, and to obtain the coal and water readings. The notches in the throttle and reverse-lever quadrants were numbered and these positions were signalled back to the dynamometer car. For finding the amount of coal used, a large quantity of weighed coal was thrown on the tender loose and then the remainder was placed in 100-lb. sacks which were used after the loose coal was exhausted, and by knowing the number of sacks used, the exact amount of coal used could be obtained. The water readings were taken by means of a float in a calibrated tank, which readings were taken before and after taking water. The losses due to injector overflow, leaks and other sources were subtracted from the total amount used.

The Burlington dynamometer car, described in the 1902 issue of the Year Book, was used throughout the tests, and

and the preceding cut, Fig. 2, illustrates a section of the dynamometer roll, showing the records taken. The movement of the roll on which the recordings take place is caused by gearing from the car axle, so proportioned that the roll moves one foot per mile. By means of the recording device of the hydraulic dynamometer, the drawbar pull is registered on this roll of paper as shown by the irregular line, the distance between this irregular line and the zero line representing the drawbar pull. The cut shown is taken from the roll of a freight train test where the scale of the pull is 6,000 lbs. to the inch.

A very handy device in the car was a switch-board, by means of which wires from the cab and pilot were connected to double-acting electro-magnets, to which were attached stylographic pens, so that when the electric circuit was closed it caused the pen to be moved out of a straight line, causing a jog or a notch.

A clock was provided which closed an electric circuit every five seconds by means of which the time was accurately recorded on the roll, as shown by the "five-second" line in the cut. This

FIG. 3. CONTINUOUS DIAGRAM WHILE ENGINE WAS STARTING UP

same pen also recorded the mile-posts and stations as well as the instant at which indicator cards were taken, the mile-posts and stations being observed by a man stationed in the cupola for that purpose, and the time of taking indicator cards being sent in from the engine

Attached to the dynamometer recording pen carriage was a mechanical integrator which, for every two square inches of area integrated, closed an electric circuit giving the "integration" line shown.

The observer in the cab, as each card was taken, by means of three push-buttons, signalled the steam pressures, throttle, and reverse-lever positions, giving the last line shown. Every notch in the reverse-lever quadrant was calibrated as to the amount of cut-off it gave the valve, so that on every card taken the exact cut-off could be found and the amount of wire-drawing determined.

Besides the apparatus already mentioned, there were in the car a duplex air gauge showing train-line and brake cylinder pressures, a recording train-line pressure gauge, a recording draft gauge for obtaining the draft in the smoke-box, a Boyer

speed recorder, a hydraulic pressure gauge, showing the drawbar pull at any instant, and electric counters for obtaining revolutions and air-pump strokes. These were all conveniently arranged on one gauge-board.

The reducing apparatus shown in the cut was designed after the one in use at the engine trials conducted at the St. Louis Exposition. This was a success in every way and is a form which can be recommended.

The indicator card shown is a continuous diagram taken while the engine was starting up and shows the variation in steam pressure and cut-off while the train was accelerating.

SOME DATA ON POWER STATION EQUIPMENT

E. H. SCOFIELD
Electrical Engineer, Twin City Rapid Transit Company

Realizing the difficulty which is experienced by a student in collecting reliable information on the details of the equipment of power stations, we have attempted to present a few of the main details of a modern plant in a form available for ready reference. While the information might be made more complete, and possibly some important items may have been omitted, it is hoped that not only will the items presented be found of interest but that the general form of presenting the information may be an aid and guide in the collection of data on other installations for the purpose of comparison.

The plant described is a steam power station which operates as an auxiliary to a water power station, on the centralized station plan, furnishing power to eight electric railway substation; each power station furnishing about one-half the total output in K.W. hours.

STEAM POWER PLANT. BUILDING:

Location, East bank of Mississippi River, just below the Tenth Avenue bridge, Minneapolis.

Size, 155′-11″ wide x 255′-2″ long x 93′-0″ high from engine-room basement to roof.

Engine-room, 67′-0″ wide, extending full length of building, and 56′-0″ high in the clear; basement floor 20′-0″ below engine-room floor.

Boiler-room, 83′-0″ wide and full length of building; basement floor 14′-0″ below boiler-room floor; boiler-room floor 4′-0″ above engine-room floor.

STACKS. 2, Alphonse Custodis System:

Hollow radial moulded brick, 162′-0″ high x 16′-0″ inside diameter; foundations 63′-0″ above the boiler-room floor; total height of stack above boiler-room, 225′-0″.

Guaranteed to stand 50 lbs. per sq. ft. and influence of atmosphere of 800° F.

COAL BUNKERS. 4, I-beam and cinder-concrete construction:

Aggregate Capacity, 2,800 tons.

Bunkers directly above boilers with light-well 14′-0″ between them, the entire length of boiler-room, thus giving a light and well-ventilated room.

Each bunker feeds 3 batteries of 2 boilers each.

The bottom of each bunker has 6 steel hoppers, which lead to coal-valves and spouts of each boiler.

COAL CRUSHER AND CONVEYOR. J. A. Mead Co.:

Overlapping gravity bucket, McCaslin type.

Coal distribution, consisting of one transverse conveyor receiving coal from crusher in basement of boiler-room and delivering it to 2 longitudinal conveyors which elevate and distribute it to 4 coal bunkers above the boilers.

Ash distribution, receiving ashes from ash-hoppers in basement under the furnace and elevating and delivering them to transverse conveyor which delivers the ashes to a hopper over coal track.

Nominal capacity (crusher and entire conveying system), 70 tons per hr.

Buckets, 24″ x 24″, travelling 100 feet per minute; buckets and links of malleable iron, shafts 1-¼″ diameter, wheels 6″ diameter, 1-½″ tread, track, 16-lb T-rail.

Drive, electric, 600 v., D.C. motors; crusher, 25 H.P.; transverse conveyor, 7-½ H.P.; longitudinal conveyor, 25 H.P.; all drives located at bottom of down-takes; all tighteners located at bottom of up-takes.

STOKERS AND FURNACE. 18, Westinghouse, Church, Kerr Co.:

Roney automatic.

Grate-rocking, inclined, engine-driven.

Fire arch, single span.

Nominal capacity, 550 H.P.; standard of 34-½ lb of water from and at 212° F. per H.P.

Overload capacity, 825 H.P. continuously.

Grate surface, 111 sq. ft.

Guaranteed to evaporate 10 lb of water from and at 212° F. per pound of bituminous coal containing 14,000 B.T.U. with ⅜″-draft without smoke. Under same conditions to evaporate 11 lb of water per pound of coal, burning New River coal containing 14,000 B.T.U.; at 825 H.P., to evaporate 9.25 lb of water per pound of coal containing 14,000 B.T.U.

BOILERS. 18, Babcock & Wilcox Co.:

Wrought steel sectional tube.

Nominal capacity, 556 H.P.

Overload capacity, 825 H.P.

Working pressure, 200 lb per sq. in.

Heating surface, 5,500 sq. ft.

Flue connection at top of setting

Pop safety valves, 2 per boiler with muffler.

Gauges, 18″ Crosby type.

Superheater, capable of producing 120° F. superheat; contained within boiler setting.

Guaranteed to operate at capacities specified with ¾″-draft and coal containing 13,000 B.T.U. per pound.

Steam and water drums, 3′-36″ diameter x 23′-3″ long.

Tubes, 21 sections, 13 tubes each, 4″ diameter, 18′ long.

Headers, forged steel.

Feed connection, 2-½″ diameter.

Steam delivery outlet, 10″ diameter.

Test, sections, 400 lb per sq. in; drums, 300 lb per sq. in.; mud-drum, 300 lb per sq. in.

Weight, total, 621,000 lb.

Floor space, per battery, 23′-5″ x 31′-0″; approximate height, 20′-4″.

SERVICE PUMPS. 2, Dean Bros., Indianapolis:

Horizontal, duplex, double-acting.

Nominal capacity, 1,200 gal. at 45 strokes per min.

Diameter, steam cylinder, 12″; water cylinder, 16″; stroke, 18″.

Guaranteed to operate with steam pressure 175 lb; 75° F. superheat water pressure, 40 lb.

Automatic governor.

Pressure gauge, 10″, Crosby.

Floor space, 39″ x 103″; approximate height, 50″.

Weight, total, 7,500 lb.

FEED WATER HEATER. 1, Stillwell-Bierce & Smith-Vaile Co.:

Open cast iron.

Guaranteed to heat 350,000 lb of water from 60° F. to 210° F. with steam at atmosphere pressure.

Filtering and settling chamber.

Thermometers in iron case, 10″ pressure-gauge.

Floor space, 11′-6″ x 6′-7″; approximate height, 16′-4″.

Weight, total, 60,000 lb.

Steam inlet, 14″; outlet, 8″.

Water inlet, 2″, with regulating valve.

BOILER FEED PUMPS. 4, Dean Bros., Indianapolis:

Vertical, single style; double-acting, twin.

Nominal capacity, 300 gal. at 40 strokes per min.

Diameter, steam cylinder, 14″; water cylinder, 10″; stroke, 24″.

Guaranteed to operate at steam pressure 175 lb; 75° F. superheat water pressure, 180 lb.

Valves and valve stems, composition metal.

Pressure gauge, 10″, Crosby.

Floor space, 84″ x 48″ per pair; approximate height, 128″.

Weight, 9,800 lb per pair.

Steam valve, 2-½″ diameter.

FEED WATER PIPING:

Two independent headers from each pair of feed-pumps, with cross connections to corresponding headers of other pairs of pumps.

Boiler connection from each header system to each boiler.

Pump connection which allows a supply of either hot or cold water to each header system.

STEAM PIPING, Wrought iron; welded-steel flanges; semi-steel fittings; high-pressure valves with by-passes on all above 8" diameter:

Main header, 16" diameter in two sections connected by 14" loop with cut-off valves at each end; cut-off valves in header providing for operating independently 1 engine with 4 boilers.

Engine connection, 2 from each header section, 1 from loop; 14" diameter, 6'-0" radius, 90° sweep; 16" "straight-line" separator supported on springs; Bundy trap; 4" auxiliary outlet; cut-off valve at header.

Boiler connection, 1 to each 4 boilers; 12" diameter, 8'-0" radius, 90° sweep to first battery; 10" diameter to second battery; 7" diameter, 3'-3" radius, 180° sweep to each boiler; cut-off valve for each boiler and at header.

Exciter connection, 4" diameter from main header, 4" "straight-line" separator; 3" diameter extension to service pumps; auxiliary 3" diameter connection to separator of one engine.

Receiver connection, 1-½" diameter from engine separator.

Condenser connection, 3" diameter from engine separator.

Feed-pump connection, 3" diameter from main header.

Stoker-engine connection, 1" diameter from main header.

EXHAUST PIPING, Cast iron and riveted sheet-steel with cast flanges; copper U-shaped expansion joints:

Main engine, 34" diameter to 30" relief-valve; 36" connection to condenser, 30" connection to header; main header to atmosphere 42" diameter; galvanized exhaust head.

Condenser, 3-way cock; 4" diameter connection to free exhaust; 4" diameter connection with double connection, one to main engine receiver, one to feed-water heater.

Auxiliary header, 8" diameter with connection to service-pump, exciter and air-pumps; 12" diameter connection to heaters; 5" diameter free exhaust to roof with 5" galvanized head.

Feed-water pumps and stoker engine exhaust into heater, stoker exhaust arranged to exhaust under grates.

MAIN ENGINES. 3, Allis-Chalmers Co.:

Vertical cross-compound engines without fly-wheel.

Nominal capacity, 5,000 indicated H.P. when using steam at 175 lb gauge pressure, and 75° F. superheat exhausting at 26" vacuum at 74-¼ r.p.m.

Overload capacity of 9,000 indicated H.P. under similar conditions at 73 r.p.m.

Diameter of H.P. cylinder, 46″; L.P. cylinder, 94″.

Stroke, 60″.

Guaranteed to develop 5,000 indicated H.P. with the steam consumption of 11-½ lb per H.P. hr. under full-load conditions.

Regulate between 76 r.p.m. at 0 load and 73 r.p.m. at 9,000 H.P., with variation of not over .09 of 1° from mean speed.

Valve gear, Reynolds-Corliss, with automatic weighted governor operating both high and low pressure sides and separate eccentrics. Motor speed control operated from switchboard.

Safety butterfly-valve operated by independent governor.

Meters, 1 steam-gauge, 1 receiver-gauge, 1 vacuum-gauge.

Floor space of 17′ x 36′; approximate height, 36 ft.

Journal, main 30″ x 60″; cross-head journal, 14″ x 14″; crank journal, 14″ x 14″.

Shaft, 33″ diameter.

CONDENSERS. 3, George F. Blake Manufacturing Co.:

Jet, vertical; twin, beam-connected; double-acting, steam; single-acting, air.

Diameter, steam cylinder, 18″; water cylinder, 48″.

Stroke, 24″.

Guaranteed to operate with a steam pressure of 175 lb and exhaust pressure of 40 lb.

Floor space, 9′ x 11′; approximate height, 15′

Foot-valves, bucket-valves, head-valves, of bronze.

Safety, automatic vacuum-brake and 5″ priming-inlet.

MAIN GENERATORS. 3, General Electric Co.:

Alternating current, 3-phase revolving field; fly-wheel type; engine-driven.

Nominal capacity, 3,500 K.W.; 13,200 volts; 153 amperes at 75 r.p.m.

Guaranteed to operate at full load, 100 per cent P.F. for 24 hrs., 35° C.; 1-¼ load, 8 hrs., 50° C.; 1-½ load, 1 hr., 42-½° C.; rise above 25° C.

Efficiency, at 1-½ load, 96 per cent; full load, 95.5 per cent; ¾ load, 94.5 per cent; ½ load, 92.5 per cent; ¼ load, 88 per cent.

Regulation, 12 per cent of full voltage.

Armature winding, formed coils; Y-connected.

Air-gap, ⅜″; number of poles, 56.

Excitation, 125 volts; full load, 100 per cent P.F., 23 K.W.; 150 per cent, full load, 50 K.W.

Insulation test, field, 1,500 volts A.C.; armature, 26,200 volts A.C. for 1 minute.

Floor space, 8'-0" x 34'-0"; approximate height, 34'-0".

Weight, total, 417,000 lb; revolving field and shaft, 315,000 lb; armature, 132,500 lb; base and foundation plates, 15,000 lb.

ENGINE-DRIVEN EXCITER. 1, 50 K. W.:

Engine, General Electric Co., 11" diameter x 11" stroke; 280 r.p.m. Vertical, single-cylinder type. Piston-valve and automatic flywheel governor. Steam pressure, 175 lb; exhaust against 45 lb pressure.

Generator, 50 K.W., General Electric Co., 6-pole, shunt-wound D.C. generator. Full load current, 400 amperes; voltage 125; commercial efficiency, full load, 90 per cent. Insulation test, 1,500 volts for 1 minute.

Floor space of set, 98" x 55": height, 99".

Weight of set, complete, 15,200 lb.

MOTOR-DRIVEN EXCITER. 1, 200 K. W.:

Induction motor, General Electric Co., 300 H.P.; 520 r.p.m.; 440 volts; 34-2/3 cycles. Full-load efficiency, 92 per cent on 100 per cent P.F. Insulation test, 2,000 volts A.C. for - minute.

D.C. Generator, General Electric Co., 200 K.W., 8-pole, shunt-wound; 520 r.p.m. Full load, 1,500 a.; voltage, 125. Commercial efficiency, 1-¼ and 1-½ full load, 91.5 per cent; ¾ full load, 90.5 per cent; ¼ load, 82 per cent. Insulation test, 1,500 volts A.C. for 1 minute.

Weight, total of set, 52,000 lb.

GENERAL SYSTEM OF HIGH-TENSION CONNECTIONS

Current from incoming lines from Water Power Station is concable to generator oil switch, to disconnecting switches, to bus-bars.

Bus-bars are divided in three sections by means of oil switches.

Current from incoming lines from Water Power Station is conveyed through disconnecting switches, oil switch and disconnecting switches in order. The three lines from Water Power Station connect, one on each bus-bar section.

Current to outgoing lines is conveyed from bus-bars through disconnecting switches, oil switch and disconnecting switches in order.

In case two or three cables supply a substation, they are connected on different sections of the bus-bars.

Static arresters are installed on outgoing and incoming lines to relieve any heavy electrical strains.

Any piece of high tension apparatus can be disconnected in order to make repairs or for inspection and cleaning.

STATION SWITCH-BOARD. General Electric Co.:

Panels,—

1 exciter generator panel, 50 K.W., 125 volts.
1 exciter generator panel, 200 K.W., 125 volts.
1 induction motor panel, 300 H.P., 13,200 volts.
3 A.C. generator panels, 3,500 K.W., 13,200 volts.
5 A.C. outgoing line panels, 4,500 K.W., 13,200 volts.
3 A.C. incoming line panels, 1,650 K.W., 13,200 volts.
1 Lincoln synchronizer and voltmeter equipment.
All panels blue Vermont marble, and instruments to have marine finish.

EXCITER GENERATOR PANEL. 50 K. W., 125 volts:

Size, 16″ x 62″ x 2″; sub-base, 16″ x 28″ x 2″.

1 600 a. ammeter.
1 500 a. D.P., S.T. switch.
1 4-pt. potential receptacle and plug.
2 600 a. fuses on back of panel.
1 field rheostat and mechanism.

EXCITER GENERATOR PANEL. 200 K. W., 125 volts:

Size, 16″ x 62″ x 2″; sub-base, 16″ x 28″ x 2″.

1 3,000 a. ammeter.
1 175 v. voltmeter.
1 4-pt. potential receptacle and plug.
1 2,000 a. D.P., S.T. switch.
2 2,000 a. fuses on back of panel.
1 field rheostat and mechanism.

INDUCTION MOTOR PANEL. 300 H. P., 13,200 volts:

Size, 16″ x 62″ x 2″; sub-base, 16″ x 28″ x 2″.

1 25 a. ammeter.
1 controlling switch for form "H" switch.
2 indicating lamps.
1 overload relay.
1 3-phase recording wattmeter.
2 25 a. current transformers.
1 T.P., S.T. 13,200 v., 300 a., form "H" electrically operated oil switch.
3 13,200 v., 300 a. disconnecting switches.

A. C. GENERATOR PANEL. 3,500 K. W., 13,200 volts:

Size, 24″ x 62″ x 2″; sub-base, 24″ x 28″ x 2″.

3 300 a. ammeter.
1 power factor indicator.
1 field ammeter.
1 D.P., S.T., 75 a., 125 v., engine-governor control switch.
1 D.P., S.T., 500 a. field switch.
1 4-pt. synchronizing receptacle and plug.
1 8-pt. potential receptacle and plug.

2 indicating lamps.
1 controlling switch for form "H" switch.
1 overload relay.
1 T.P., S.T. 13,200 v., 300 a., form "H" electrically operated oil switch.
3 13,200 v., 300 a. disconnecting switch.
1 3-phase recording wattmeter.
2 13,200/110 volt potential transformers.
4 300 a. current transformers.
1 field rheostat and mechanism.

A. C. OUTGOING LINE PANEL. 4,500 K. W., 13,200 volts:

Size, 16" x 62" x 2"; sub-base, 16" x 28" x 2".

3 400 a. ammeters.
1 controlling switch for form "H" switch.
1 overload relay.
2 indicating lamps.
1 T.P., S.T., 13,200 v., 300 a., form "H" electrically operated oil switch.
6 13,200 v., 300 a. disconnecting switches.
1 3-phase recording wattmeter.
2 current transformers.

A. C. INCOMING LINE PANEL. 1,650 K. W., 13,200 volts:

Size, 16" x 62" x 2"; sub-base, 16" x 28" x 2".

1 150 a. ammeter.
1 controlling switch for form "H" switch.
2 overload relays.
2 indicating lamps.
1 T.P., S.T. 13,200 v., 300 a., form "H" electrically operated oil switch.
3 13,200 v., 300 a., disconnecting switches.
2 current transformers.

LINCOLN SYNCHRONIZER AND VOLTMETER Equipment:

Size, 16" x 28" x 1-½"; mounted on swinging bracket.

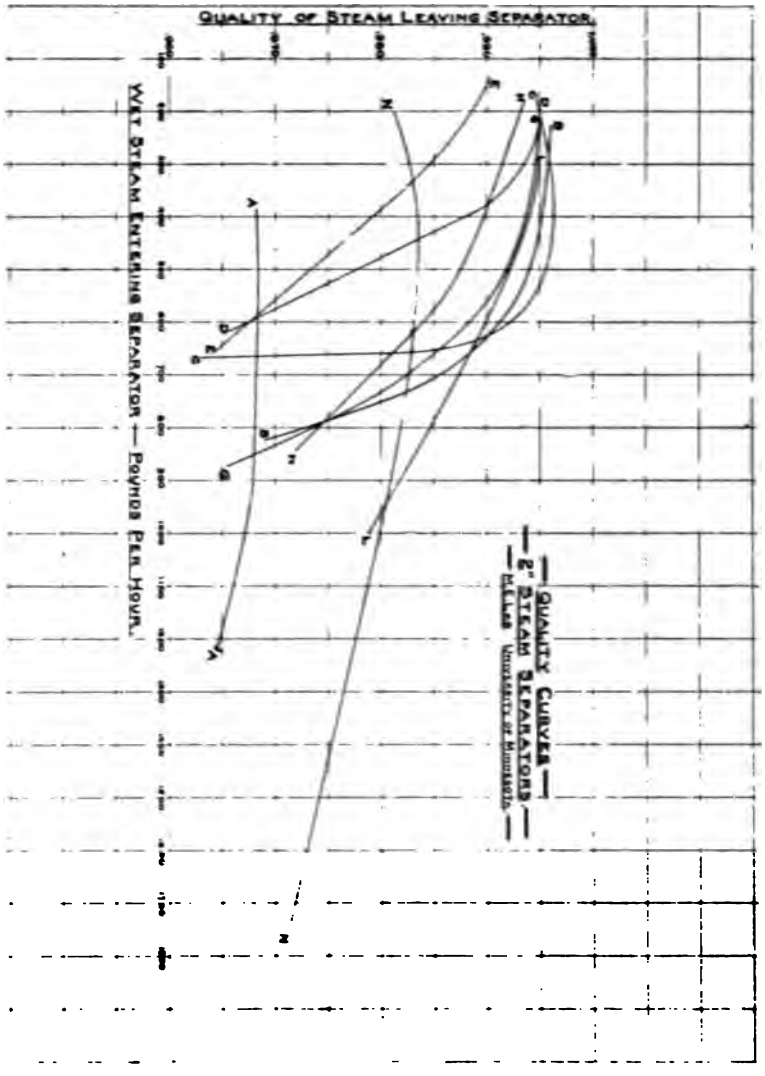
1 Lincoln synchronizer.
2 synchronizing lamps.
2 175 v. voltmeters with kilovolt scale.
2 200 watt, 13,200/110 v. potential transformers.

STEAM SEPARATOR TESTS

WILLIAM H. KAVANAUGH, *M.E.*

Assistant Professor of Mechanical Engineering, University of Minnesota.

During the past two years a number of efficiency tests of steam separators have been made in the Mechanical Engineering


QUALITY OF STEAM LEAVING SEPARATOR
WET STEAM ENTERING SEPARATOR — POUNDS PER HOUR
QUALITY CURVES
2" STEAM SEPARATORS
U. OF M.
UNIVERSITY OF MINNESOTA

Laboratory of the University. The separators tested have been, for the most part, the two-inch sizes of the best known types on the market.

MECHANICAL ENGINEERING LABORATORY. UNIVERSITY OF MINNESOTA.

2-INCH STEAM SEPARATORS.

Tables Showing Results of Tests.

Separator.	Test Number	Duration Minutes	Steam Press. Gauge.	WEIGHTS.				PerCt. Moisture in Steam.		Quality of Steam		Loss of Steam Press. in Sep'r
				Steam	Water	T'l Water & Steam Enter'g Separator						
				Cond'd	Trapped	Dur. Test	Per Hour	Ent'g	Lea'g	Ent'g	Lea'g	Lbs.
A Horizontal.	1	10	90.9	61.0	2.65	63.65	381.9	7.13	3.09	.9287	.9691	.....
	2	10	86.3	30.0	34.23	64.23	385.4	54.8	3.37	.452	.9663	.....
	3	10	83.2	64.5	2.00	66.50	399.0	5.98	3.07	.9402	.9693	.....
	4	10	83.6	68.5	1.95	70.45	422.7	5.68	2.98	.9432	.9702	.....
	5	10	88.5	39.5	32.83	72.33	434.0	47.30	3.47	.5270	.9653	.....
	6	10	90.6	72.0	2.75	74.75	448.5	6.10	3.02	.9390	.9698	.....
	7	10	86.9	66.9	25.58	92.48	554.9	31.80	3.39	.6820	.9661	.....
	8	10	90.0	91.5	3.10	94.43	567.6	7.41	3.24	.9259	.9676	.....
	9	10	85.0	94.5	2.35	96.85	581.1	5.50	3.20	.9450	.9680	.....
	10	10	77.9	87.8	24.50	112.30	673.8	24.4	3.25	.7560	.9675	.....
	11	10	74.7	116.0	1.70	118.70	712.2	4.23	2.83	.9577	.9698	.....
	12	10	67.1	113.4	10.70	124.10	744.6	1.12	2.82	.8880	.9748	.....
	13	10	56.8	114.0	22.40	136.40	818.4	18.90	2.90	.8110	.9661	.....
	14	10	81.3	126.0	26.20	152.20	913.2	19.90	2.80	.8010	.9710	.....
	15	10	86.2	186.7	1.86	188.50	1131.4	4.70	3.68	.9530	.9632	.....
	16	10	73.0	197.0	7.20	204.20	1225.2	6.70	3.23	.9330	.9677	.34
B Horizontal.	1	6	49.	13.5	9.	22.5	225	60.00	.39	.4000	.9961	.....
	2	10	64.6	32.5	18.	50.5	333	66.00	.42	.3400	.9958	.....
	3	10	63.5	32.5	36.5	69.0	414	47.50	.90	.5250	.9910	.....
	4	10	65.4	30.	53.	83.	498	36.50	.25	.6360	.9975	.....
	5	10	70.4	33.	53.	86.	516	39.00	.92	.6100	.9909	.....
	6	10	47.5	27.	61.	88.	528	31.00	.40	.6900	.9960	.....
	7	10	47.1	28.	70.	98.	588	28.60	1.10	.7140	.9890	.....
	8	10	80.6	35.	67.	102.	612	34.50	.35	.6340	.9965	.25
	9	10	83.2	29.	100.1	129.1	780	24.20	2.44	.7580	.9756	.....
	10	10	82.5	28.	109.	137.	822	22.90	3.08	.7710	.9692	.....
												.....
C Horizontal.	1	10	60.3	23.00	6.44	29.44	176.64	10.00	.54	.9000	.9946	.....
	2	10	43.6	30.00	7.62	37.62	225.72	20.00	.50	.8000	.9950	.....
	3	10	50.6	34.00	7.62	41.62	249.72	17.00	.40	.8300	.9960	.....
	4	10	30.7	32.00	18.75	50.75	304.50	38.00	.30	.6400	.9970	.....
	5	10	49.1	42.00	9.75	51.75	310.50	17.50	.50	.8250	.9950	.....
	6	10	49.5	46.50	9.75	56.25	337.50	17.50	.40	.8300	.9960	.....
	7	10	47.7	34.00	23.56	57.56	345.36	43.80	.50	.5620	.9956	.....
	8	10	48.8	49.00	28.12	77.12	462.72	34.50	.40	.6550	.9960	.....
	9	10	54.05	51.00	28.12	79.12	474.72	34.00	.50	.6600	.9950	.....
	10	10	50.5	60.00	27.50	87.50	525.00	31.00	.70	.6900	.9930	.....
	11	10	65.1	64.00	26.18	90.18	541.08	29.00	.40	.7100	.9960	.....
	12	10	71.6	75.00	25.68	100.68	604.08	25.00	.90	.7500	.9910	.....
	13	10	67.2	86.00	19.63	105.63	631.75	18.00	.90	.8200	.9910	.....
	14	10	80.4	78.75	30.25	109.00	654.00	26.00	1.40	.7400	.9860	.....
	15	10	78.9	91.00	20.00	111.00	666.00	15.30	3.70	.8470	.9630	.50
D Horizontal.	1	10	52.3	17.0	13.41	30.41	182.46	46.30	.50	.5570	.9950	.....
	2	10	59.3	28.5	12.66	41.16	246.9	31.00	.50	.6900	.9950	.....
	3	10	64.6	38.5	14.84	53.34	320.	28.40	.70	.7160	.9930	.....
	4	15	49.2	58.7	25.63	84.38	337.3	31.00	.80	.6900	.9920	.....
	5	15	71.5	87.7	5.00	92.7	370.8	6.10	1.00	.9390	.9900	.....
	6	15	76.1	95.5	4.95	100.45	401.8	5.90	1.10	.9410	.9890	.....
	7	15	82.8	104.7	7.81	112.5	450.3	8.60	2.00	.9140	.9800	.....
	8	10	80.0	83.0	7.06	90.06	540.3	10.20	2.50	.8980	.9750	.....
	9	10	82.6	85.5	11.5	97.0	582.	14.70	3.20	.8530	.9680	.....
	10	10	88.2	90.75	10.56	101.31	607.8	13.50	3.50	.8650	.9650	.....
	11	10	81.1	99.5	3.62	103.12	618.7	6.40	3.00	.9360	.9700	1.00
E Horizontal.	1	10	77.3	17.6	4.87	22.47	134.8	23.40	.97	.7760	.9903	.....
	2	10	77.83	24.0	5.31	29.31	175.86	20.00	1.10	.8000	.9890	.....
	3	10	77.93	31.7	5.25	36.95	221.7	15.80	1.24	.8423	.9876	.....
	4	15	71.59	75.7	7.31	83.01	332.04	10.20	1.50	.8980	.9850	.....
	5	15	74.82	88.75	4.63	93.43	373.7	7.30	2.34	.9270	.9766	.....
	6	15	87.71	100.20	6.37	106.57	426.3	8.30	2.48	.9170	.9752	.....
	7	10	82.84	67.4	4.56	71.96	431.7	8.20	1.90	.9180	.9810	.....
	8	15	81.81	117.8	5.81	123.31	494.4	7.00	2.40	.9300	.9760	.....
	9	12.5	71.50	111.75	7.06	118.81	570.3	9.20	3.24	.9080	.9676	.....
	10	15	76.70	136.10	15.62	151.72	606.8	13.20	3.29	.8680	.9671	.....
	11	15	88.33	155.00	10.68	165.68	662.7	8.50	3.02	.9150	.9638	1.00

STEAM SEPARATOR TESTS

WILLIAM H. KAVANAUGH, *M.E.*
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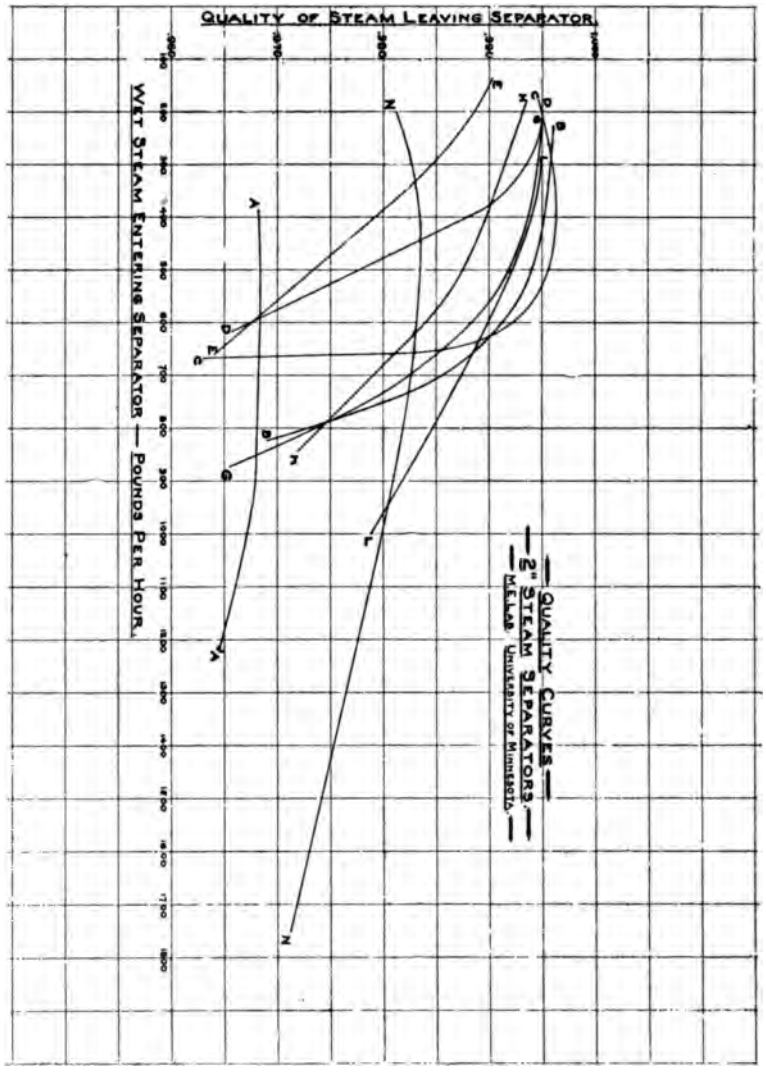
During the past two years a number of efficiency tests of steam separators have been made in the Mechanical Engineering


QUALITY OF STEAM LEAVING SEPARATOR
WET STEAM ENTERING SEPARATOR — POUNDS PER HOUR.
— QUALITY CURVES —
— 2" STEAM SEPARATORS —
— M.E. LAB. UNIVERSITY OF MINNESOTA —

Laboratory of the University. The separators tested have been, for the most part, the two-inch sizes of the best known types on the market.

MECHANICAL ENGINEERING LABORATORY. UNIVERSITY OF MINNESOTA.

2-INCH STEAM SEPARATORS.

Tables Showing Results of Tests.

Separator.	Test Number	Duration Minutes	Steam Press. Gauge.	WEIGHTS.				Per Ct. Moisture in Steam.		Quality of Steam		Loss of Steam Press. in Sep'r
				Steam	Water	T'l Water & Steam Enter'g Separator						
				Cond'd	Trapped	Dur. Test	Per Hour	Ent'g	Lea'g	Ent'g	Lea'g	Lbs.
A Horizontal.	1	10	90.9	61.0	2.65	63.65	381.9	7.13	3.09	.9287	.9691	.....
	2	10	86.3	30.0	34.23	64.23	385.4	54.8	3.37	.452	.9663	.....
	3	10	83.2	64.5	2.00	66.50	399.0	5.98	3.07	.9402	.9693	.....
	4	10	83.6	68.5	1.95	70.45	422.7	5.68	2.98	.9432	.9702	.....
	5	10	88.5	39.5	32.83	72.33	434.0	47.30	3.47	.5270	.9653	.....
	6	10	90.6	72.0	2.75	74.75	448.5	6.10	3.02	.9390	.9698	.....
	7	10	86.9	66.9	25.58	92.48	554.9	31.80	3.39	.6820	.9661	.....
	8	10	90.0	91.5	3.10	94.43	567.6	7.41	3.24	.9259	.9676	.....
	9	10	85.0	94.5	2.35	96.85	581.1	5.50	3.20	.9450	.9680	.....
	10	10	77.9	87.8	24.50	112.30	673.8	24.4	3.25	.7560	.9675	.....
	11	10	74.7	116.0	1.70	118.70	712.2	4.23	2.83	.9577	.9698	.....
	12	10	67.1	113.4	10.70	124.10	744.6	1.12	2.82	.8880	.9748	.....
	13	10	56.8	114.0	22.40	136.40	818.4	18.90	2.90	.8110	.9661	.....
	14	10	81.3	126.0	26.20	152.20	913.2	19.90	2.80	.8010	.9710	.....
	15	10	86.2	186.7	1.86	188.50	1131.4	4.70	3.68	.9530	.9632	.....
	16	10	73.0	197.0	7.20	204.20	1225.2	0.70	3.23	.9330	.9677	.34
B Horizontal.	1	6	49.	13.5	9.	22.5	225	60.00	.39	.4000	.9961	.....
	2	10	64.6	32.5	18.	50.5	333	66.00	.42	.3400	.9958	.....
	3	10	63.5	32.5	36.5	69.0	414	47.50	.90	.5250	.9910	.....
	4	10	65.4	30.	53.	83.	498	36.50	.25	.6360	.9975	.....
	5	10	70.4	33.	53.	86.	516	39.00	.92	.6100	.9909	.....
	6	10	47.5	27.	61.	88.	528	31.00	.40	.6900	.9960	.....
	7	10	47.1	28.	70.	98.	588	28.60	1.10	.7140	.9890	.....
	8	10	80.6	35.	67.	102.	612	34.50	.35	.6340	.9965	.25
	9	10	83.2	29.	100.1	129.1	780	24.20	2.44	.7580	.9 56	.....
	10	10	82.5	28.	109.	137.	822	22.90	3.08	.7710	.9692	.....
												.....
C Horizontal.	1	10	60.3	23.00	6.44	29.44	176.64	10.00	.54	.9000	.9946	.....
	2	10	43.6	30.00	7.62	37.62	225.72	20.00	.50	.8000	.99-0	.....
	3	10	50.6	34.00	7.62	41.62	249.72	17.00	.40	.8300	.9960	.....
	4	10	30.7	32.00	18.75	50.75	304.50	38.00	.30	.6400	.9970	.....
	5	10	49.1	42.00	9.75	51.75	310.50	17.50	.50	.8250	.9950	.....
	6	10	49.5	46.50	9.75	56.25	337.50	17.50	.40	.8300	.9960	.....
	7	10	47.7	34.00	23.56	57.56	345.36	43.80	.50	.5620	.9950	.....
	8	10	48.8	49.00	28.12	77.12	462.72	34.50	.40	.6550	.9960	.....
	9	10	54.05	51.00	28.12	79.12	474.72	34.00	.50	.6600	.9950	.....
	10	10	56.5	60.00	27.50	87.50	525.00	31.00	.70	.6900	.9930	.....
	11	10	65.1	64.00	26.18	90.18	541.08	29.00	.40	.7100	.9960	.....
	12	10	71.6	75.00	25.68	100.68	604.08	25.00	.90	.7500	.9910	.....
	13	10	67.2	86.00	19.63	105.63	631.75	18.00	.90	.8200	.9910	.....
	14	10	80.4	78.75	30.25	109.00	654.00	26.00	1.40	.7400	.9860	.....
	15	10	78.9	91.00	20.00	111.00	666.00	15.30	3.70	.8470	.9630	.50
D Horizontal.	1	10	52.3	17.0	13.41	30.41	182.46	46.30	.50	.5570	.9950	.....
	2	10	59.3	28.5	12.66	41.16	246.9	31.00	.50	.6900	.9,50	.....
	3	10	64.6	38.5	14.84	53.34	320.	28.40	.70	.7160	.9930	.....
	4	15	49.2	58.7	25.63	84.38	337.3	31.00	.80	.6900	.9920	.....
	5	15	71.5	87.7	5.00	92.7	370.8	6.10	1.00	.9390	.9900	.....
	6	15	76.1	95.5	4.95	100.45	401.8	5.90	1.10	.9410	.9890	.....
	7	15	82.8	104.7	7.81	112.5	450.3	8.60	2.00	.9140	.9800	.....
	8	10	80.0	83.0	7.06	90.06	540.3	10.20	2.50	.8980	.9750	.....
	9	10	82.6	85.5	11.5	97.0	582.	14.70	3.20	.8530	.9680	.....
	10	10	88.2	90.75	10.56	101.31	607.8	13.50	3.50	.8650	.9650	.....
	11	10	81.1	99.5	3.62	103.12	618.7	6.40	3.00	.9360	.9700	1.00
E Horizontal.	1	10	77.3	17.6	4.87	22.47	134.8	23.40	.97	.7760	.9903	.....
	2	10	77.83	24.0	5.31	29.31	175.86	20.00	1.10	.8000	.9890	.....
	3	10	77.93	31.7	5.25	36.95	221.7	15.80	1.24	.8420	.9876	.....
	4	15	71.59	75.7	7.31	83.01	332 04	10.20	1.50	.8980	.9850	.....
	5	15	74.82	88.75	4.63	93.43	373.7	7.30	2.34	.9270	.9766	.....
	6	15	87.71	100.20	6.37	106.57	426.3	8.30	2.48	.9170	.9752	.....
	7	10	82.84	67.4	4.56	71.96	431.7	8.20	1.90	.9180	.9810	.....
	8	15	81.81	117.8	5.81	123.31	494.4	7.00	2.40	.9300	.9760	.....
	9	12.5	71.50	111.75	7.06	118.81	570.3	9.20	3.24	.9080	.9676	.....
	10	15	76.70	136.10	15.62	151.72	606.8	13.20	3.29	.8680	.9671	.....
	11	15	88.33	155.00	10.68	165.68	662.7	8.50	3.02	.9150	.9638	1.00

MECHANICAL ENGINEERING LABORATORY. UNIVERSITY OF MINNESOTA

2-Inch Steam Separators

Tables Showing Results of Tests

Separator	Test Number	Duration Minutes	Steam Press. Gauge	WEIGHTS. Steam Cond'd	Water Trapped	Total Water & Steam Entering Separator Dur. Test	Per Hour	PerCt. Moisture in Steam Ent'g	Lea'g	Quality of Steam Ent'g	Lea'g	Loss of Steam Press. in Sep'r Lbs.
G Horizontal	1	10	76.8	24.00	11.25	35.25	211.50	32.30	.60	.6770	.9940	.....
	2	10	72.3	34.00	7.25	41.25	247.50	17.80	.40	.8220	.9960	.....
	3	10	72.8	40.00	12.12	52.12	312.72	23.80	.70	.7620	.9930	.....
	4	10	80.4	46.00	7.37	53.37	320.22	14.10	.70	.8590	.9930	.....
	5	10	75.7	50.50	13.93	64.43	386.58	22.00	.60	.7800	.9940	.....
	6	10	75.7	50.00	23.75	73.75	442.50	32.50	.60	.6750	.9940	.....
	7	10	72.0	56.25	28.12	84.37	506.22	33.30	.90	.6670	.9910	.....
	8	10	79.8	67.50	17.81	85.31	511.86	21.00	.70	.7900	.9930	.....
	9	10	78.0	61.25	28.62	89.87	539.22	32.50	1.00	.6750	.9900	.....
	10	10	78.5	61.00	29.69	90.69	544.14	31.30	.90	.6670	.9910	.....
	11	10	57.1	94.25	7.25	101.50	609.00	9.00	1.40	.9100	.9860	.....
	12	10	54.4	108.50	15.37	123.87	743.22	13.80	1.95	.8620	.9805	.....
	13	10	82.2	127.25	11.25	138.50	831.00	11.00	3.10	.8900	.9690	.....
	14	10	80.8	132.75	7.31	140.06	840.36	8.50	3.00	.9150	.9700	.....
	15	10	66.6	129.00	16.62	145.62	873.72	14.00	3.30	.8600	.9670	.25
H Horizontal	1	10	84.0	15.0	15.63	30.63	183.78	51.30	.60	.4870	.9940	.....
	2	10	90.0	21.5	17.70	39.20	235.20	45.50	.70	.5450	.9930	.....
	3	10	47.3	42.5	13.60	56.10	336.60	25.00	1.20	.7500	.9880	.....
	4	10	82.0	53.0	10.46	63.46	380.76	17.50	1.20	.8250	.9880	.....
	5	10	84.8	16.5	51.40	67.90	407.40	76.00	.80	.2400	.9920	.....
	6	10	65.8	58.0	10.15	68.15	408.90	15.60	.80	.8440	.9920	.....
	7	10	62.2	70.5	6.93	77.40	464.40	10.20	1.30	.8980	.9870	.....
	8	10	84.0	70.0	9.65	79.65	477.90	13.20	1.20	.8680	.9880	.....
	9	10	63.0	78.0	7.53	85.53	513.18	9.80	1.10	.9020	.9890	.....
	10	10	80.5	95.0	8.40	103.40	620.40	9.50	1.60	.9020	.9840	.....
	11	10	80.0	95.0	9.71	104.71	628.46	10.90	1.80	.8910	.9820	.....
	12	10	84.0	111.0	9.15	120.15	720.90	9.60	2.20	.9040	.9780	.....
	13	10	81.8	112.0	9.27	121.27	728.62	9.80	2.30	.9020	.9770	.....
	14	10	86.3	129.0	11.15	140.15	840.90	10.60	2.90	.8940	.9710	.....
	15	10	80.0	135.0	5.77	140.77	844.62	6.40	2.50	.9360	.9750	1.00
L Horizontal	1	10	46.0	20.	29.5	49.5	297.	60.00	.40	.4000	.9960	.....
	2	10	47.0	20.	22.2	42.2	313.	52.80	.66	.4720	.9934	.....
	3	15	48.55	69.	43.5	112.5	450.	38.50	.70	.6150	.9930	.....
	4	10	56.2	38.5	37.5	76.	456.	49.50	.22	.5050	.9958	.....
	5	10	53.4	48.	30.5	78.5	471.	38.50	.42	.6150	.9958	.....
	6	10	65.6	52.	28.	80.	480.	35.00	.83	.6500	.9917	.....
	7	10	68.3	58.	36.	94.	564.	38.50	.97	.6170	.9903	.....
	8	15	71.4	91.	58.	149.	596.	39.00	1.20	.6100	.9880	.....
	9	10	53.6	88.	35.	123.	738.	28.50	1.24	.7150	.9876	.....
	10	7	39.5	68.	19.	87.	746.	22.00	1.77	.7800	.9823	.....
	11	10	60.5	91.	34.5	125.5	753.	27.50	1.40	.7250	.9860	.....
	12	10	54.	95.	31.5	126.5	759.	25.50	1.10	.7450	.9890	.....
	13	10	63.	143.	23.5	166.5	999.	14.00	2.11	.8600	.9789	.10
N Horizontal	1	10	90.0	12.25	27.64	39.89	238.0	69.86	1.91	.3014	.9809	.....
	2	10	82.1	27.00	26.87	53.87	322.0	50.99	2.21	.4901	.9779	.....
	3	10	81.75	56.00	3.63	59.63	357.7	7.24	1.23	.9276	.9877	.....
	4	10	81.33	65.00	2.71	67.71	405.2	5.70	1.76	.9430	.9824	.....
	5	10	80.94	65.75	2.95	68.60	412.2	5.56	1.32	.9444	.9868	.....
	6	10	90.16	71.00	2.70	73.70	442.2	5.41	1.81	.9459	.9819	.....
	7	10	89.19	73.50	3.83	77.33	464.0	18.82	1.46	.8118	.9854	.....
	8	10	88.6	69.00	30.95	99.95	599.7	32.46	2.18	.6754	.9782	.....
	9	10	66.5	73.50	28.01	101.51	609.0	31.93	1.64	.6807	.9836	.....
	10	10	84.5	70.50	34.57	105.07	630.4	33.02	1.91	.6698	.9809	.....
	11	10	88.5	99.20	32.58	131.78	790.7	26.24	2 02	.7376	.9798	.....
	12	10	88.5	116.70	28.00	144.70	868.2	21.00	2.05	.7900	.9795	.....
	13	10	67.87	123.50	24.75	144.25	890.0	11.21	1.68	.8879	.9832	.....
	14	5	82.0	79.30	12.95	92.25	1117.0	16.13	2.43	.8387	.9757	.....
	15	10	68.0	173.50	15.85	189.35	1135.0	10.71	1.98	.8929	.9802	.....
	16	10	90.83	226.50	2.16	228.66	1368.9	3.31	2.40	.9669	.9760	.....
	17	10	85.5	283.50	8.80	292.30	1753.8	15.43	2.92	.8457	.9708	.25

The tables presented herewith show the results of these tests, the names of the separators tested being omitted for obvious reasons. The quality curves have been plotted from the data given in the tables. The general method of conducting the tests was as follows:

The pipe supplying the separator with steam was surrounded with a water-jacket by means of which the percentage of moisture in the entering steam was varied. The water removed from the steam by the separator was trapped out and weighed. The steam leaving the separator was condensed in a surface condenser and weighed. The quality or dryness of the steam leaving the separator was determined by means of a throttling calorimeter. The quality of steam entering the separator was calculated from the weights of the water trapped out and the steam condensed and the quality of the steam leaving the separator.

The loss of pressure in the separator was determined by means of a mercury manometer; connection to one leg of the manometer being made to the steam pipe close up to the steam inlet of the separator, while the other leg was connected to the steam pipe close up to the steam outlet. During the tests all parts of the apparatus were covered with hair felt, and every precaution was taken to secure accuracy of results.

The tests show that the quality of the steam delivered by the separators is independent of the percentage of moisture in the entering steam, within the limits of the capacity of the separator. The capacities of the different separators are well shown by the quality curves.

SOME REPRESENTATIVE CURVES FROM STREET CAR TESTS

The following are some curves reproduced from a thesis on street car testing written this year by E. Anderson, C. E. Boman, K. A. Simmon and J. W. Wood.

These curves were obtained either directly or indirectly by means of a recording instrument built by these men and which they used in conducting a series of tests on one of the new cars, No. 1070, of the Twin City Rapid Transit Company.

FIG. 1. A PORTION OF ORIGINAL CURVES AS RECORDED BY THE INSTRUMENT

Fig. 1 shows a small portion of an original curve taken by the recording instrument. This was taken on Lyndale Avenue while the car was going from Groveland to Lake Street. As far as Twenty-sixth Street, line voltage was recorded on the upper curve. On passing Twenty-sixth Street, speed measurement was switched onto the instrument. The curve shows two starts and two stops in a distance of about four blocks. The lower curve shows current consumption of the car. Values are read from these curves by means of a templet corresponding to the scale of the instrument used. One is made to read volts, another, speed in miles per hour, and a third, current.

Fig. 2 shows five accelerating curves which were taken in order from a curve sheet and plotted to scale. These need hardly any

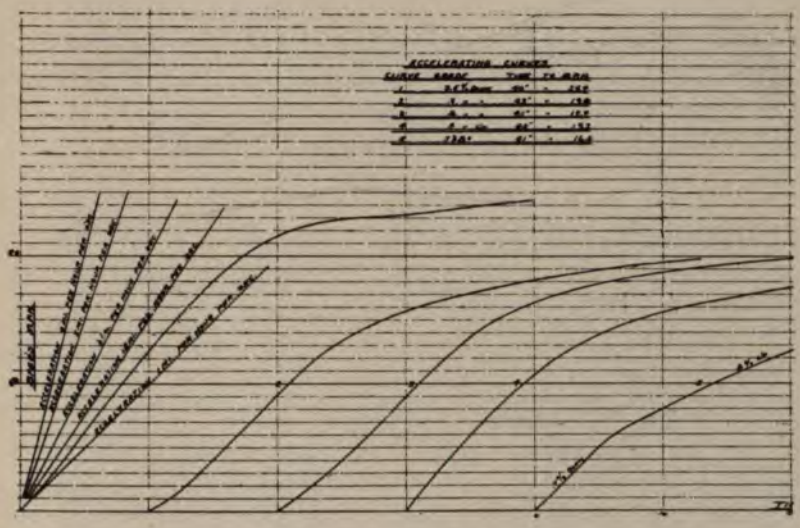


FIG. 2. Accelerating Curves

explanation, but attention might be called to curve 2. This shows a rounding at the ends and indicates no sudden variation in speed. With such a rounding at the ends of the curves a high rate of acceleration is possible without discomfort to passengers.

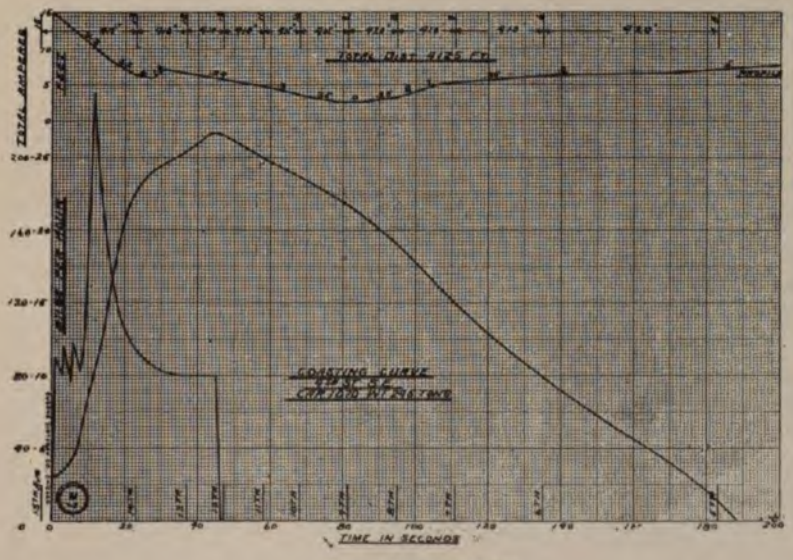


FIG. 3. Coasting Curve

Fig. 3 shows a coasting curve, the current consumed by the car and the profile of the track. By closely following the coasting curve the influence of the grades on speed is clearly shown. The current curve shows some of the kicks in the current due to re-

sistances in the series control of the motor as the controller is thrown on. The motors were thrown from full series to full parallel, so no kicks appear in the parallel control. Current was used for 46 seconds and reached a maximum of 235 amperes, which is well within the limit as the circuit breakers of the cars are set at 300 amperes.

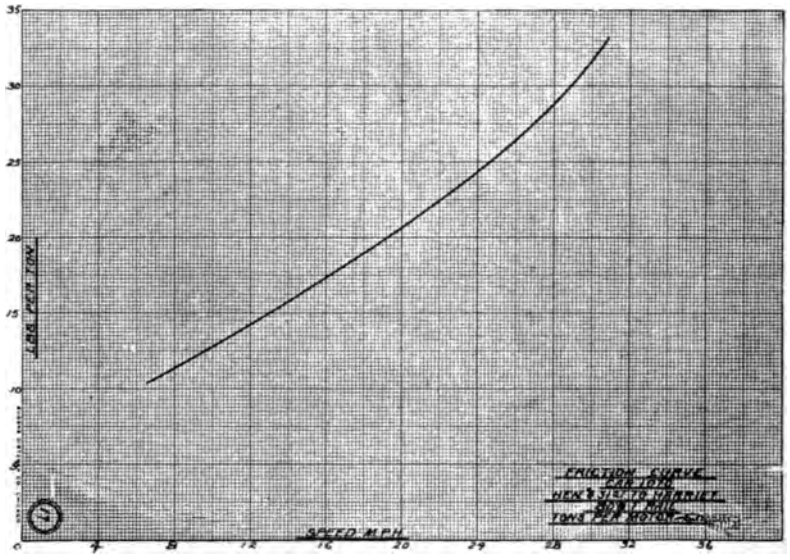


FIG. 4. Friction Curve

Fig. 4 is a friction curve and is one of the most important curves to be obtained in street car testing. This particular curve was obtained on the Harriet line, between Hennepin and Thirty-first Street and the end of the line, where there is a track that is good and comparatively clean, and the tractive effort is not as high as on other lines.

From the friction curve and the characteristic curves of the motors the speed grade curve, or the curve showing the maximum speed obtainable on different grades, can be computed. From this speed grade curve and the profile of the track, schedules can be "made up," and as a matter of fact that is the way they are obtained.

The friction curve offers a basis for figuring the energy used by a car in making a trip and is of value in several other ways.

If time and space permitted, these curves might be discussed at length and various others shown, especially friction curves, which vary considerably for different car lines of the city.

FLEXURE OF REINFORCED CONCRETE BEAMS IN THE LIGHT OF RECENT RESEARCH

FRANK H. CONSTANT

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The practical designer is perplexed by the number of formulæ at present in use to determine the dimensions and strength of reinforced concrete beams. Nearly all such formulæ start with the stress strain diagram for concrete in compression, and are built up by mechanical principles into perfectly rational equations that are accurate if the fundamental assumptions are correct. They all assume that sections plane before bending remain plane after bending; they all neglect certain indeterminate though

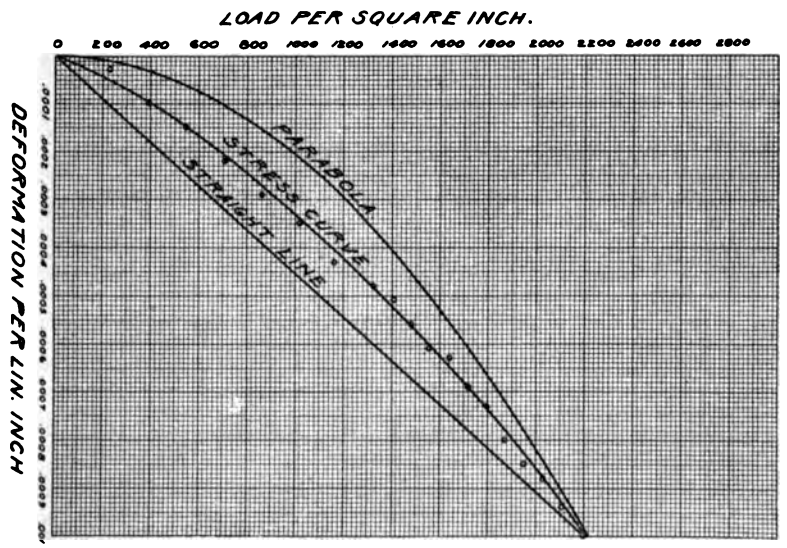
LOAD PER SQUARE INCH.
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
DEFORMATION PER LIN. INCH
PARABOLA
STRESS CURVE
STRAIGHT LINE

PLATE I.

none the less real factors, such as the lag of the steel, the tensile strength of the concrete, the shrinkage stresses in concrete and steel, so that the best of formulæ must be more or less approximate; and they disagree, in general, only in the nature of the stress strain curve. The parabola and the straight-line are the curves most commonly used, and the formulæ derived from them are called, accordingly, the parabolic and the straight-line formulæ.

Having found the point of difference between the various methods, it would seem that an agreement could be reached by

getting accurate laboratory data. But unfortunately the necessity for making an accurate investigation of the elastic properties of concrete was not apparent until recently, and the meager data available were often conflicting. Some of the earliest tests seemed to indicate that the stress curve is nearly a parabola, and hence the parabolic formula gained a strong foothold. Recent work, however, is clearly indicating that up to half the ultimate strength of concrete, at least, the stress curve is practically a straight line. Plates I and II give the results of the tests upon

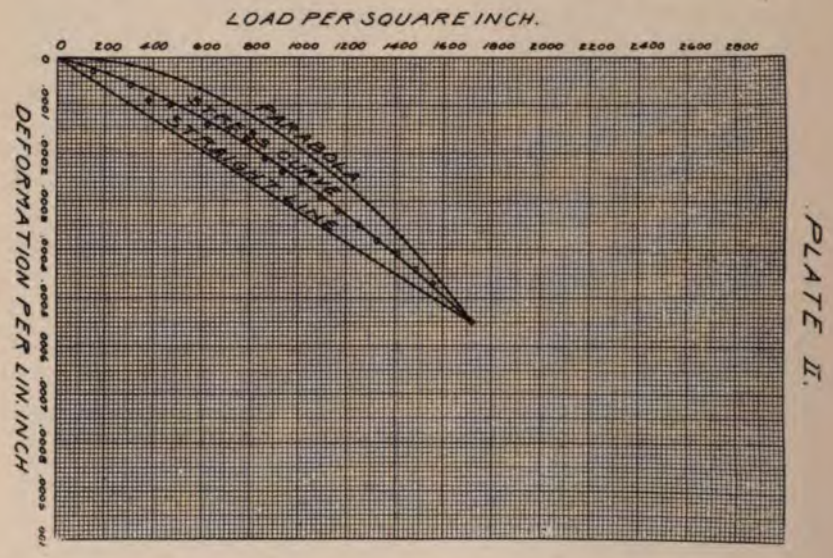
LOAD PER SQUARE INCH.
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
DEFORMATION PER LIN. INCH
PARABOLA
STRAIGHT LINE

PLATE II.

two blocks, eight inches square and twenty-four inches high, made in our own structural laboratory by members of the Senior class. It is seen that the true curve lies between a parabola and a straight line. The proportions of concrete were 1 : 2 : 4, and the age was about three months.

But even if an agreement can be reached upon the stress curve for concrete, doubt might still arise as to whether it may be applied to the case of flexure of reinforced beams. Tests upon beams would seem to be a more direct solution of the problem of flexure than upon compression blocks. It will be seen later that the stress curve is quite sufficient to meet the needs of the problem. Yet it is quite natural that experimenters should turn their attention to tests upon beams, and the most recent work has been along this line. The stretch and compression of bottom and top fibers in the beam are accurately measured by extensometers, and from the deformations thus obtained, together with the stress strain curves for concrete in pure tension and com-

pression, previously found, the extreme fiber stresses are at once deduced and a pretty complete knowledge of the distribution of the internal stresses over the section of the beam is gained. Although such an anlysis requires the stress curve, to start from, yet if the wrong curve is used the results will be inconsistent and will not check up. Hence the two methods are intimately associated and the investigator who has both data at hand has several guideposts to lead him to the correct analysis.

Wishing, if possible, to arrive at the true theory of flexure for reinforced beams, the writer turned to the widely known and excellent tests of Professor Talbot upon full-size beams, published in Bulletin No. 1 of the University of Illinois Engineering Experiment Station, as the most available and reliable data at hand. The fiber deformations are given, together with the dimensions and loading of the beams. The concrete was a 1 : 3 : 6 mixture, age about sixty days, and the coefficient of elasticity was taken, for the present investigation, to be 2,000,000. Being predisposed to the straight-line formula, the writer has really fitted this theory to the data given for Professor Talbot's beams, to see whether consistent and correct results could be obtained. Data are here given for eight of the nineteen beams, these eight being quite representative of the entire set.

There are two tables for each beam. The beams were all twelve inches wide, thirteen and one-half inches deep, and the steel bars were embedded one and one-half inches above the bottom. The meaning of the several columns is as follows:

In Table I: Column 1. The load applied by the testing machine and producing the maximum bending movement given in Col. 10.

Column 2. The extreme fiber stress in the concrete on the compression side, found by multiplying the fiber deformation by 2,000,000.

Column 3. The stress per square inch in the steel bars, found by multiplying the fiber deformation in the plane of the steel by 30,000,000 (except for beam 16, where 31,000,000 was used).

Column 4. The resultant compressive stress above the neutral axis, assuming the intensity of stress to vary between the neutral axis and the outer fiber according to the straight-line law. The mean stress is, accordingly, one half of Col. 2, and the product of the mean stress and the section of the beam in compression gives Col. 4.

Column 5. The total stress in the steel, found by multiplying the stress per square inch into the area of the steel.

Column 6. The distance of the neutral axis from the top of the beam, found from the laboratory data.

Column 7. The moment of the total compression about the neutral axis, found by multiplying Col. 4 into two-thirds of Col. 6. 6.

Column 8. The moment of the tension in the steel, found by multiplying Col. 5 into the difference between Col. 6 and twelve inches, viz: the distance of the center of the steel below the neutral axis.

Column 9. The total moment of resistance, neglecting the tensile resistance of the concrete.

Column 11. The ratio of the internal moment of resistance thus found to the actual bending moment.

Glancing at the table as a whole, it is evident that the difference between Col. 5 and Col. 4 should give the amount of tension in the concrete (here neglected), and that the moment of this tension (lever arm unknown), when added to Col. 9, should equal the bending moment. Now if the table is based upon the correct theory, several facts are evident. First, Col. 5 should always be less than Col. 4, and the difference should become relatively less as the loading increases; until at the time when the cracks on the tension side have extended to the neutral axis the stress in the steel should be quite equal to the compression above the neutral axis. While some of the beams fulfill this test very closely, they all satisfy it as well as could be expected. Secondly, the moment of the tension in the concrete should be relatively much less for heavy than for light loads, partly because the tension is less, and partly because the cracking of the lower part of the beam rapidly decreases the lever arm for tension in the uncracked part near the neutral axis. The manner of distribution of the tension throughout the sound concrete below the axis, and the depth of penetration of the tensile cracks, make the tensile lever arm a very uncertain quantity. By making certain reasonable assumptions for these unknown factors, the writer was able to get an approximate value for the tensile moment (not given in this article). It was found that, except for the lightest loads, this moment was relatively insignificant, that it rapidly decreased for heavier loads, and that there is not much error in neglecting it entirely. For this reason it has not been considered worth while to reproduce here the investigations along this line.

Finally, the ratio of the computed to the bending moment, given in Col. 11, should always be less than unity, and it should be smallest for light loads, owing to the omitted tensile moment, and should rapidly approach unity as the loads increase. Col. 11 does not, in general, fulfill this test as well as could be expected. The ratio is too small for the lightest loads, while it generally runs above unity for the heaviest. Corresponding to

a value of 500 or 600 in Col. 2, it is about .80. It reaches unity when Col. 2 is between 1000 and 1500.

Table II is an analysis of each beam fro mthe straight-line formula, and depends upon the laboratory data only for the compressive stress per square inch in the outer fiber, which is copied from Col. 2 of the first table. As this stress was obtained directly from extenso-meter readings, it is not likely to be very far wrong for each loading.

Column 3. Stress per square in the steel. It will be noted that these values run higher than in the first table, which is due to the fact that the formula makes the steel take all of the tension.

Column 4. The distance of the neutral axis from the top of the beam, computed from formula. This is a constant value for all loadings, whereas in the first table it varied according to the relative importance of the tension in the concrete, gradually decreasing under heavier loads but never attaining the computed elevation for Table II.

Column 5. The moment of resistance of the beam by formula, neglecting the tensile resistance of the concrete.

Column 6. The bending moment, copied from Table 1.

Column 7. The ratio of Col. 5 to Col. 6. It will be noticed that this ratio is higher throughout than in Table 1, and while rather low in some cases, in general does not err so far upon the side of safety as to destroy the usefulness of the formula, or more, in fact, than might be considered advisable to cover imperfections in the concrete. But should the designer feel that his formula is too safe, he may easily correct for it by taking slightly higher unit stresses, knowing at the same time that the higher value he takes for Col. 2, the more nearly will the ratio of Col. 7 approach unity, that is, the more nearly does his formula fit.

Had a stress curve lying midway between a straight line and a parabola been used for both tables it is probable that the final ratios would have been more satisfactory. It must not be forgotten, however, that the neglect of the tensile resistance of the concrete is always an error on the side of safety, whatever theory is applied. Moreover, such a curve would involve such complicated equations as to make its use practicable only after previously working out tables of constants which the busy designer can quickly apply. The writer feels that the straight-line formula is sufficiently accurate for everyday use to obviate the necessity for any more complicated method.

The straight-line formulæ will now be given for convenient reference:

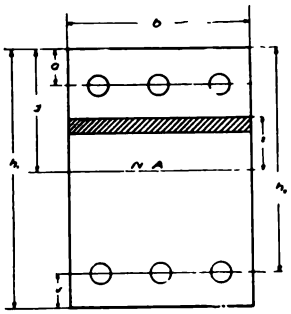

Fig. 1

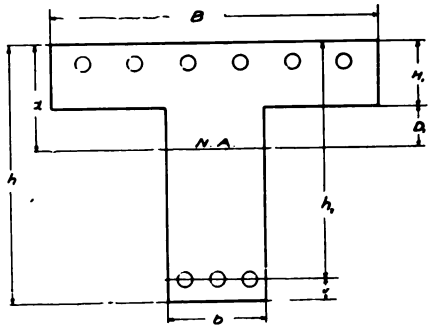

Fig. 2

Let h_1=depth of beam.

d_1=distance of neutral axis below top of beam.

b=width of beam at distance z from neutral axis=constant width for rectangular beam.

a=distance of center of steel in compression below top of beam.

v=distance of center of steel in tension above bottom of beam.

h_2=distance of center of steel in tension below top of beam.

A_1 A_2=areas of steel in compression and tension respectively.

E_1, E_2=coefficients of elasticity of concrete and steel respectively.

k_1=compressive unit stress in top fiber of beam.

c=compressive unit stress in A_1.

t=tensile unit stress in A_2.

M=moment of resistance of beam.

p=ratio of area of steel to area of section above the center of the steel.

In any case two equations are needed, one giving the position of the neutral axis, namely, d_1, and the other giving the moment of resistance, M. For the general case of beams of any cross section and with steel on both sides,

$$\frac{k_1}{2}\int_o^{d_1} b\,dz + cA_1 - tA_2 = o \qquad (1)$$

$$t = \frac{E_2}{E_1} \cdot \frac{h_2 - d_1}{d} \cdot k_1 \qquad (2)$$

$$c = \frac{E_2}{E_1} \cdot \frac{d_1 - a}{d_1} \cdot k_1 \qquad (3)$$

$$\int_o^{d_1} b\,dz + \frac{2E_2}{E_1}\left\{\frac{(d_1 - a)}{d_1} \cdot A_1 - \frac{(h_2 - d_1)}{d_1} \cdot A_2\right\} = o \qquad (4)$$

Equation (4) is perfectly general.

Case I. Rectangular beams, steel on both sides. Equation (4) becomes,

$$bd_1^2 + \frac{2E_2}{E_1}\left\{(d_1 - a)A_1 - (h_2 - d_1)\ A_2\right\} = o \qquad (5)$$

whence,

$$d_1 = -\frac{E_2}{E_1 b}(A_1+A_2) + \sqrt{\left\{\frac{E_2}{E_1 b}(A_1+A_2)\right\}^2 + \frac{2E_2}{E_1 b}(A_1 a + A_2 h_2)} \qquad (6)$$

Case II. Rectangular beams, steel on tension side only.

$$d_1 = -\frac{E_2 A_2}{E_1 b} + \sqrt{\left\{\frac{E_2 A_2}{E_1 b}\right\}^2 + \frac{2E_2 A_2 h_2}{E_1 b}} \qquad (7)$$

Case III. Tee beams, steel on both sides (Fig. 2). Equation (4) becomes,

$$B\int_o^{d_1} dz + b\int_o^{D_1} dz + \frac{2E_2}{E_1}\left\{\frac{d_1 - a}{d_1}A_1 - \frac{h_2 - d_1}{d_1}\ A_2\right\} = o \qquad (8)$$

Integrating and putting $D_1 = d_1 - H_1$

$$BH_1 d_1 + b(d_1 - H_1)d_1 + \frac{2E_2}{E_1}\left\{(d_1 - a)A_1 - (h_2 - d_1)\ A_2\right\} = o$$

whence,

$$d_1 = -\frac{H_1(B-b)}{2b} + \frac{E_2(A_1 + A_2)}{E_1 \quad b} + \sqrt{\left\{\frac{H_1(B-b) + \frac{2E_2}{E_1}(A_1+A_2)}{2b}\right\}^2 + \frac{2E_2}{E_1 b}(A_1 a + A_2 h_2)} \qquad (9)$$

Case IV. Tee beam, steel on tension side only.

$$d_1 = -\frac{H_1(B-b)}{2b} - \frac{E_2 A_2}{E_1 b} + \sqrt{\left\{\frac{H_1(B-b)}{2b} + \frac{E_2 A_2}{E_1 b}\right\}^2 + \frac{2E_2 A_2 h_2}{E_1 b}}$$

The general equation of moment of resistance, whatever the shape of the section, is,

$$M = \frac{k_1}{d_1} I_1 + \frac{t}{h_2 - d_1} I_2 \qquad (11).$$

I_1 and I_2 are the moments of inertia respectively of the concrete in compression and of the steel, whatever its shape or distribution throughout the section, each taken about the neutral axis of the beam.

Equations (11) and (2) give,

$$M = \frac{k_1}{d_1}\left(I_1 + \frac{E_2}{E_1} I_2\right) \qquad (12).$$

Case I. Rectangular beams, steel both sides.

$$M = \frac{k_1}{d_1}\left\{\frac{bd_1^3}{3} + \frac{E_2}{E_1}\left[A_1\ (d_1 - a)^2 + A_2\ (h_2 - d_1)^2\right]\right\} \qquad (13).$$

Case II. Rectangular beams, steel on tension side only.

$$M = \frac{k_1}{d_1}\left\{\frac{bd_1^3}{3} + \frac{E_2}{E_1} A_2\ (h_2 - d_1)^2\right\} \qquad (14).$$

Case III. Tee beams, steel both sides.

$$I_1 = \frac{BH_1^3}{3} + BH_1 (d_1 - H_1)^2 + \frac{b(d_1 - H_1)^3}{3}$$

$$M = \frac{k_1}{d_1} \left\{ \frac{BH_1^3}{3} + BH_1(d_1 - H_1)^2 + \frac{b(d_1 - H_1)^3}{3} + \frac{E_2}{E_1}[A_1 (d_1 - a)^2 + A_2 (h_2 - d_1)^2] \right\} \quad (15)$$

Case IV. Tee beams, steel on tension side only.

$$M = \frac{k_1}{d_1} \left\{ \frac{BH_1^3}{3} + BH_1 (d_1 - H_1)^2 + \frac{b(d_1 - H_1)^3}{3} + \frac{E_2}{E_1} A_2 (h_2 - d_1)^2 \right\} \quad (16)$$

The designer will find it very convenient to put these equations into tabular form, that he may get their values at a glance. Case II will be taken as an example of the method:

Let p=ratio of area of steel to section of beam above the center of the steel.

h_2=distance from top of beam to center of steel.

Then $A_2 = p\ b\ h_2$.

Substituting these values in (7) and (14),

$$d_1 = h_2 \left\{ -\frac{E_2}{E_1} p + \sqrt{ (\frac{E_2}{E_1} p)^2 + \frac{2 E_2 p}{E_1} } \right\}$$

whence,

$$d_1 = m\ h_2 \quad (17).$$

$$M = b\ k_1 \left\{ \frac{d_1^2}{3} + \frac{E_2}{E_1} \frac{p h_2}{d_1} (h_2 - d_1)^2 \right\}$$

$$= b\ k_1 h_2^2 \left\{ \frac{m^2}{3} + \frac{E_2}{E_1} \frac{p}{m} (1 - m)^2 \right\}$$

whence,

$$M = n\ b\ k_1\ h_2^2 \quad (18).$$

From (2),

$$t = \frac{E_2}{E_1} \frac{1 - m}{m} k_1.$$

whence,

$$t = r k_1 \quad (19).$$

The parabolic formulæ for the same case are as follows:

$$d_1 = h_2 \left\{ -\frac{3}{4} \frac{E_2}{E_1} p + \sqrt{ (\frac{3}{4} \frac{E_2}{E_1} p)^2 + \frac{3}{2} \frac{E_2}{E_1} p } \right\}$$

whence,

$$d_1 = m\ h_2 \quad (17^1).$$

$$M = b\ k_1\ h_2^2 \left[\frac{5 m^2}{12} + \frac{E_2}{E_1} \frac{p}{m} (1 - m)^2 \right]$$

whence,

$$M = n\ b\ k_1\ h_2^2 \qquad (18^1)$$

$$t = \frac{E_2}{E_1}\ \frac{1-m}{m}\ k_1.$$

whence,

$$t = rk_1 \qquad (19^1).$$

$\frac{E_2}{E_1}$ may be taken at 10 for a 1 : 2 : 4 concrete, at 12 for a 1 : 2 : 5, and at 15 for a 1 : 3 : 6. Tables A, B, and C are based upon these three ratios and k_1 equal to 500, for both straight-line and parabolic formulæ. To use the tables, select b_1 h_2 and p: opposite p find nk_1 and t. Equation (18) will give M. Two or three trials will give not only a safe but an economical beam. For any other value of k_1 the coefficients in the columns headed nk_1 and rk_1 should be changed proportionately. k_1 will vary with the proportions of the concrete and the use the structure is to be put to.

Beam No. 2

Reinforcement, 5-½" corrugated bars, area = 1.co sq. inch

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis from top	Moments				Ratio Col. 9 / Col. 10
	Comp.	Steel	Comp.	Steel		Comp.	Steel	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
3000	240	5100	7200	5100	4.96	23800	35900	59700	84000	71
5000	360	6900	11400	6900	5.27	40000	46400	86400	140000	62
8000	740	18000	20300	18000	4.58	61900	133600	195500	224000	87
10000	1020	25800	27400	25800	4.47	81600	194300	275900	280000	98
13000	1440	36600	38400	36600	4.45	114000	276400	390400	364000	107
16000	1920	47400	52000	47400	4.53	157000	354000	511000	448000	114
19000	2600	59100	74500	59100	4.77	237000	427300	664300	532000	125

Beam No. 2

Table II

Loads	Stress per sq. in.		Neutral Axis	Moments		Ratio Col. 5 / Col. 6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
3000	240	6330	4.35	66690	84000	79.5
5000	360	9500	4.35	99900	140000	71.5
8000	740	19500	4.35	205300	224000	91.5
10000	1020	26900	4.35	283000	280000	103.
13000	1440	38000	4.35	400000	364000	110.
16000	1920	50600	4.35	533000	448000	119.
19000	2600	68600	4.35	721000	532000	136.

Beam No. 3

Reinforcement, 3-½" corrugated bars, area = 0.60 sq. inches

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis	Moments				Ratio Col. 9 / Col. 10
	Comp.	Steel	Comp.	Steel		Comp.	Steel.	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
2000	100	1500	3600	900	6.0	14400	5400	19800	56000	35.6
4000	140	2100	5040	1260	6.0	20160	7560	27720	112000	24.8
6000	460	11400	12420	6840	4.5	37260	51300	88560	168000	52.5
10000	1140	39900	24600	24000	3.6	59000	201600	260600	280000	93.
12000	1440	52200	30240	31320	3.5	72500	266200	338700	336000	101.

Beam No. 3

Table II

Loads	Steel per sq. in.		Neutral Axis	Moments		Ratio Col. 5 / Col. 6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
2000	100	3550	3.56	23070	56000	41.5
4000	140	4980	3.56	32300	112000	29.0
6000	460	16350	3.56	106000	168000	63.0
10000	1140	40500	3.56	263000	280000	94.

Beam No. 4

Reinforcement, 5-½" Kahn Bars, area = 2.00 sq. inches

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis	Moments				Ratio Col. 9 / Col. 10
	Comp.	Steel	Comp.	Steel		Comp.	Steel	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
5000	320	4200	12300	8400	6.4	52900	47000	99900	140000	71.
8000	600	9000	21600	18000	6.0	86400	108000	194400	224000	87.
11000	900	15000	30200	30000	5.6	111700	192000	303700	308000	98.5
16000	1400	24600	46200	49200	5.5	171000	320000	491000	448000	110.
18000	1640	27600	55100	55200	5.6	204000	353000	557000	504000	111.
20000	1900	31800	63800	63600	5.6	236000	407000	643000	560000	115.
21000	2000	33900	67200	67800	5.6	248600	434000	682600	588000	116.

Beam No. 4

Table II

Loads	Stress per sq. in.		Neutral Axis	Moments		Ratio Col. 5 / Col. 6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
5000	320	5410	5.6	109500	140000	78.3
8000	600	10150	5.6	205400	224000	91.5
11000	900	15230	5.6	308000	308000	100.
16000	1400	23700	5.6	479000	448000	10[illegible].
18000	1640	27750	5.6	561000	504000	111.
20000	1900	32150	5.6	650000	560000	116.
21000	2000	33800	5.6	685000	588000	116.

Beam No. 5

3-½" Kahn bars, area = 1.20 sq. inches.

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis	Moments				Ratio Col. 9 / Col. 10
	Comp.	Steel	Comp.	Steel		Comp.	Steel	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
3000	200	3300	6840	3960	5.7	26000	24950	50950	84000	60.5
5000	380	6300	13000	7560	5.7	49400	47600	97000	140000	69.5
8000	760	16200	22340	19440	4.9	74500	138000	212500	224000	95.
10000	1000	21900	30000	26300	5.0	100000	184000	284000	280000	101.
13000	1400	30300	42000	36360	5.0	140000	254500	394500	364000	109.

Beam No. 5

Table II

Loads	Stress per sq. in.		Neutral Axis	Moments		Ratio Col. 5 / Col. 6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
3000	200	4660	4.7	58400	84000	69.5
5000	380	8850	4.7	111000	140000	79.5
8000	760	17700	4.7	222000	224000	99.
10000	1000	23300	4.7	292000	280000	104.
13000	1400	32600	4.7	409000	364000	112.

Beam No. 9

3-½" Ransome (twisted) ars, barea = 0.75 s. inches.

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis	Moments				Ratio Col.9 / Col.10
	Comp.	Steel	Comp.	Steel		Comp.	Steel	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
4000	200	2400	8000	1800	6.67	35200	9600	44800	112000	40
8000	760	21000	19150	15750	4.2	53600	123000	176600	224000	79
10000	1040	30000	24950	22500	4.0	66500	180000	246500	280000	88
13000	1500	42900	36900	32200	4.1	99600	254000	353600	364000	97
15000	1780	53100	42700	39800	4.0	114000	320000	434000	420000	103
18000	2360	66900	58100	50200	4.1	157000	396500	553500	504000	110

Beam No. 9

Table II

Loads	Stress per sq. in.		Neutral Axis	Moments		Ratio Col.5 / Col.6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
4000	200	6230	3.9	50000	112000	44.5
8000	760	23700	3.9	190000	224000	85.
10000	1040	32400	3.9	260000	280000	93.
13000	1500	46700	3.9	375000	364000	103.
15000	1780	55500	3.9	495000	420000	118.
18000	2360	73500	3.9	590000	504000	117.

Beam No. 15

3-¼" Thacher bars, area = 1.20 sq. inches

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis	Moments				Ratio Col. 9 / Col. 10
	Comp.	Steel	Comp.	Steel		Comp.	Steel	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
4000	200	2400	8000	2880	6.7	35200	15260	50460	112000	45
8000	620	12300	19300	14760	5.2	67500	100400	167900	224000	75
10000	880	18600	26400	22320	5.0	87100	156200	243300	280000	87
13000	1200	27000	34600	32400	4.8	111000	233000	344000	364000	95
16000	1600	39600	43200	47520	4.5	129600	356000	485600	448000	108

Beam No. 15

Table II

Loads	Stress per sq. in.		Neutral Axis	Moments		Ratio Col. 5 / Col. 6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
4000	200	4660	4.7	58400	112000	52
8000	620	14450	4.7	181000	224000	81
10000	880	20500	4.7	257000	280000	92
13000	1200	28000	4.7	350500	364000	96
16000	1600	37300	4.7	467300	448000	105

Beam No. 16

3-½" Square rods, orer = 0.75 sq inches

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis	Moments				Ratio Col. 9 / Col. 10
	Comp.	Steel	Comp.	Steel		Comp.	Steel	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
4000	260	3600	10000	2700	6.4	42700	15120	57820	112000	51.5
5000	420	7440	14100	5580	5.6	62600	35700	88300	140000	63.
6000	640	14900	18430	11170	4.8	59000	80400	139400	168000	83.
8000	940	25000	24800	18750	4.4	72660	142500	215160	224000	96.
10000	1220	32550	32200	24400	4.4	94300	185400	279700	280000	100.

Beam No. 16

Table II

Loads	Stress per sq. in.		Neutral Axis	Moments		Ratio Col. 5 / Col. 6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
4000	260	8100	3.9	65000	112000	58
5000	420	13100	3.9	105000	140000	75
6000	640	20000	3.9	160000	168000	95
8000	940	29300	3.9	235000	224000	105
10000	1220	38000	3.9	305000	280000	109

Beam No. 27

4-¾" Square rods, area = 2.25 sq. inches

Table I

Loads	Stress per sq. in.		Total Stress		Neutral Axis	Moments				Ratio Col. 9 / Col. 10
	Comp.	Steel	Comp.	Steel		Comp.	Steel	Total	B. M.	
1	2	3	4	5	6	7	8	9	10	11
4000	220	1500	10560	3375	8.0	56300	13500	69800	112000	62.5
6000	374	3480	16600	7830	7.4	81800	36000	117800	168000	70.
8000	568	6450	23500	14500	6.9	108000	73950	181950	224000	81.5
10000	777	9840	30300	22140	6.5	131200	121800	253000	280000	90.5
12000	980	13200	37050	29700	6.3	155600	169300	324900	336000	97.
16000	1400	19860	52080	44700	6.2	215000	259300	474300	448000	106.
20000	1856	25220	69040	56740	6.2	285100	329000	614100	560000	110.
25000	2560	35400	95200	79640	6.2	393200	462000	855200	700000	122.

Beam No. 27

Table II

Loads	Stress per sq. in.		Neutral Axis	Moments		Ratio Col. 5 / Col. 6
	Comp.	Steel		Formula	B. M.	
1	2	3	4	5	6	7
4000	220	3450	5.87	77800	112000	69.5
6000	374	5860	5.87	132300	168000	79.
8000	568	8900	5.87	201000	224000	90.
10000	777	12180	5.87	275000	280000	98.5
12000	980	18800	5.87	346700	336000	103.
16000	1400	21940	5.87	495300	448000	111.
20000	1856	29100	5.87	656600	560000	117.
25000	2560	40100	5.87	906000	700000	130.

Table A $\frac{E_2}{E_1}=10$

STRAIGHT-LINE				PARABOLIC		
p	$m=\frac{d_1}{h_2}$	$k_1 n$	$k_1 r=t$	$m=\frac{d_1}{h_2}$	$k_1 n$	$k_1 r$
.0025	.200	46.5	20000	.176	54.7	23500
.005	.272	61.5	13350	.239	72.4	15900
.006	.291	65.7	12100	.259	77.5	14300
.007	.310	69.1	11100	.276	82.6	13150
.008	.328	72.9	10200	.292	86.4	12150
.009	.343	76.0	9550	.306	89.9	11300
.010	.359	78.7	8900	.319	93.7	10650
.011	.372	81.5	8450	.332	96.6	10000
.012	.384	83.7	7970	.344	99.6	9550
.013	.396	86.9	7570	.355	102.4	9100
.014	.407	87.9	7270	.365	105.1	8700
.015	.418	89.8	6960	.375	107.2	8300
.016	.428	91.6	6680	.384	109.7	8000
.017	.437	93.5	6420	.393	111.6	7700
.018	.446	95.0	6170	.402	113.8	7460
.019	.455	96.6	5970	.410	115.6	7200
.020	.463	98.0	5790	.418	117.4	6970
.022	.479	100.0	5440	.433	120.6	6550
.024	.492	103.0	5150	.447	123.9	6200
.026	.506	105.0	4870	.459	126.7	5870
.028	.519	107.4	4630	.471	129.2	5600
.030	.531	109.1	4420	.482	131.6	5360
.035	.557	113.3	3960	.508	137.1	4830
.040	.580	117.0	3620	.531	141.8	4400
.045	.600	120.0	3330	.551	145.7	4070
.050	.618	122.6	3090	.568	149.4	3790

Table B $\frac{E_2}{E_1}=12$

.0025	.217	50.2	21650	.191	59.0	25340
.005	.291	65.8	14600	.258	77.8	17200
.006	.314	70.2	13100	.279	83.5	15510
.007	.334	74.1	11950	.297	88.2	14200
.008	.352	77.8	11050	.314	92.1	13110
.009	.369	80.8	10250	.329	96.6	12250
.010	.384	83.6	9650	.343	99.8	11470
.011	.398	86.5	9100	.357	102.9	10810
.012	.411	89.0	8600	.369	106.1	10260
.013	.424	90.8	8150	.380	108.9	9780
.014	.435	93.1	7800	.391	111.5	9370
.015	.446	95.1	7450	.402	113.8	8950
.016	.457	96.8	7150	.411	116.2	8610
.017	.467	98.6	6850	.420	118.3	8280
.018	.476	100.0	6600	.430	120.1	7960
.019	.484	101.7	6400	.438	122.1	7680
.020	.493	103.0	6150	.446	124.0	7450
.0225	.513	106.2	5700	.466	127.8	6870
.025	.530	109.4	5300	.482	131.7	6440
.0275	.547	111.7	4950	.499	134.7	5980
.030	.561	114.3	4700	.512	138.2	5710
.035	.588	118.1	4200	.539	143.3	5090
.040	.611	121.6	3800	.561	148.0	4680
.045	.631	124.5	3500	.582	151.6	4290
.050	.648	127.3	3250	.600	155.0	4000

Table C $\frac{E_2}{E_1}=15$

.0025	.240	54.8	23800	.211	64.6	28020
.005	.319	71.4	16010	.283	84.7	18970
.006	.343	76.3	14360	.306	90.3	17000
.007	.365	80.2	13050	.325	94.7	15550
.008	.384	83.7	12050	.343	100.0	14350
.009	.402	86.7	11660	.361	103.6	13300
.010	.418	89.8	10410	.375	107.6	12530
.011	.432	92.4	9860	.388	110.9	11810
.012	.443	95.5	9420	.401	114.0	11180
.013	.459	97.1	8850	.414	116.7	10640
.014	.471	99.2	8410	.425	119.4	10150
.015	.482	101.3	8070	.436	121.9	9690
.016	.493	103.0	7700	.446	122.6	9300
.017	.503	105.0	7410	.456	125.8	8890
.018	.513	106.3	7120	.466	127.9	8600
.019	.525	107.0	6790	.474	129.6	8320
.020	.536	108.3	6500	.483	132.0	8000
.0225	.552	111.9	6100	.503	135.7	7400
.025	.571	114.8	5650	.520	139.1	6920
.0275	.584	118.0	5350	.536	142.9	6490
.030	.600	120.0	5000	.549	145.6	6150
.035	.625	124.1	4500	.576	150.8	5510
.040	.650	126.9	4040	.600	155.0	5000
.045	.675	128.9	3620	.622	158.0	4570
.050	.700	129.9	3210	.636	162.7	4280

AN OIL GAS PLANT

R. S. KING

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The high price of coal during the last few years has caused engineers to look for some substitute. One particular type of new fuel process which appears to be in favor with some promoters is what is known among gas engineers as the "greased-air process." Briefly described, this process consists in blowing air through some petroleum product, usually gasoline. Under proper conditions it is possible to make a very fair combustible in this way, and gas machines of this type furnishing gas for illuminating isolated country houses have been in use for many years. There is, therefore, nothing novel or revolutionary in the process, but the dangers in connection with it and various uncertainties in its operation have tended to discourage its use.

The figure is taken from the photograph of a plant installed to furnish gas for the drying stoves in a foundry and for the hardening and tempering furnaces in a blacksmith shop. The small plant on the left-hand side has a capacity of 20,000 cu. ft. of gas per hour; the plant on the right has a capacity of 40,000 cu. ft. per hour.

The process of gas manufacture consists in forcing warm air through oil contained in the series of small tanks. The oil used is a crude distillate of petroleum of about 68° to 70° grav-

ity, being an oil product having a wider range of vaporization than kerosene.

The oil is fed from a small tank into the generators by a pump, and is kept in continuous circulation through the tank and generators. The object of this is to secure a uniform quality of gas and to utilize the oil as completely as possible. The small supply tank is usually outside the building and under ground and contains one day's supply only. The air from the blower is delivered to a 30-inch air-tank containing a steam heating coil. From this it passes to two groups of generators, each group consisting of four tanks. The oil fills only about 25 to 30 per cent of the tanks, and the small pipe near the bottom is for the circulating system and to maintain a uniform level. The air-pipe is led below the surface of the oil, and horizontal perforated plates having coke laid on them keep the oil from rising and blowing. The gaseous mixture of air and oil escapes from the top of the tank and is piped to the bottom of the next tank, and so on throughout the series. Beyond the generators is a gas tank or reservoir 30 in. in diameter, from which the supply is piped to the furnaces and stoves. The generating plant is automatic in its action, the production varying in accordance with the demand. The gas is manufactured only as fast as required, so that no gas-holder is required for storage. The above brief description covers the plant and operation as it was delivered, guaranteed to work satisfactorily. Below will be given some of the many troubles and difficulties and the remedies applied.

Theoretically, the circulating system was fine, but with the crude distillate petroleum used the gas would get weaker from the start, because the lighter oils were first vaporized, leaving a heavy oil which the air would not take up. This residue or oil left over averaged about 20 per cent of the original amount. The first remedy was to use gasoline, which cut down the loss due to non-vaporizing oils, but its increased cost about equalled the saving. A further remedy was finally applied by heating the gasoline to 120° or 150° F. before putting in the generators, and by doing away with the circulating system. The per cent of heavy oil left is very small. In place of the circulating system a sight feed system was installed, so that the oil was fed into the generators only as used.

Before the circulating system was abandoned, the pipes would fill up with fine coke, due to the grinding action of the coke contained in the generators for breaking up the spray of oil and keeping it from being mechanically carried over into the

system. This was overcome by using brickbats in place of the coke.

The gas was supposed to be dry and free from excess oil. The condensed oil varied from day to day, and would seem to collect along the bottom of the pipes and then make a rush and fill the furnaces and stoves with oil, causing many delays in the manufacturing processes. Although the pipes were well slanted, the oil would not drain back, so it became necessary to install a number of drip-tanks which were connected to a pump and pumped back to the plant.

The quality of the gas made from oil from the same tank car would vary from day to day. The author made some experiments to determine if this was due to the variation of moisture in the air, but the data secured was insufficient to entirely prove this to be the cause, although it indicated it.

A test made on this plant, after the changes noted above were made, gave the following results:

Oil used in 10 hours	556 gal.
Gas made,	276,610 cu. ft.
Power to run blower	51.6 H.P.
Oil per 1000 cu. ft. of gas,	2.01 gal.
App. cost of power per 1000 cu. ft.	.05 cents.
Cost of oil per 1000 cu. ft.	.224 cents.
Cost of labor per 1000 cu. ft.	.008 cents.
Total cost per 1000 cu. ft.,	.282 cents.

The calorific value of this gas varied from 375 to 400 B.T.U.

For piping this fuel gas to any furnace or stove, a check-valve and screen should be placed in the gas line, as close to the mixing tee as possible. When first installed, the screens alone were used in this plant except at the generating plant itself. Once the gas became poor and the flame burned back to a screen, causing it to become red-hot. For some reason the power was shut down on the plant and an explosion immediately followed, tearing open the pipe lines but leaving the generating plant intact, due to the closing of the check-valve at the generating plant before the flame reached it. A better protection than a single wire screen is to make a roll of the screen about six inches long and place in the pipe, then if one end heats, the rest of the roll prevents the propagation of the flame.

This gas is being successfully used in tempering furnaces of all kinds, and is used to some extent for melting of brass and drying of brass moulds. It has been used somewhat in blacksmith forges, but up to the present time there has not been a

successful smith forge made that burns the gas economically.

A test made on a case-hardening furnace using this gas showed a consumption of 1441 cu. ft. per hour. 4562 cu. ft. of gas was sufficient to heat (for case-hardening) about 750 lbs. of small punched pieces of steel. The approximate temperature in this furnace, obtained by means of a fire-clay ball pyrometer, was 1610° F.

As to the efficiency of the gas, seven out of ten replies received from inquiries sent out by the "Engineering News" to companies using this gas were favorable. In two cases it effected a saving of 50 and 75 per cent, as compared with city gas. The efficiency in the latter case was due to the pressure under which the gas was burned and its purity, the gas being used for case-hardening. One of the unfavorable replies states that the system is not as yet considered efficient. Another reply states that its value for forge work has not as yet been demonstrated and that so far it is uneconomical. The third company in its reply says it cannot recommend the system.

YEAR BOOK

of

THE ENGINEERS' SOCIETY

1906

The Engineering Society has been exceedingly fortunate in being favored with a series of lectures and short talks.

At the beginning of the year we held an open meeting for the purpose of arousing interest among the members of the Engineering College who were not members of the Society. Short talks were given by Dean F. S. Jones, Professors W. R. Hoag, J. J. Flather, F. H. Bass, and W. H. Kavanaugh who outlined the purpose of the Society and presented ideas pertaining to its welfare.

On February 23d, 1906, Mr. L. F. Parker delivered an illustrated lecture on the Columbia Improvement Company at Taylor's Falls, Minn. Mr. Parker outlined in a general way the method of construction of the dam and power plant covering civil, mechanical, and electrical features.

On April 19th, 1906, Mr. J. T. Fanning, C.E., read a paper on "Skilled Observations" before the Society. The article was very interesting and Mr. Fanning by request kindly permitted the YEAR BOOK editors to publish it in this issue.

Mr. J. R. Cravath on April 27th, 1906, delivered a lecture before the Society on "Illuminating Engineering" which was very interesting and highly appreciative.

A new idea was inaugurated in the Society during the last semester in which a program by members of the Society followed each regular business session. The scheme worked admirably and it is hoped that the plan will be carried out more elaborately next year. Programs were given as follows:

Mar. 16, 1906.	"A Cantilever Bridge,".....E. B. Alsop, '06.
	"The Calorimetric Determination of the Heat-Value of Gas Engine Exhaust"....F. E. Mattison, '06.
	"The Electrolytic Rectifier".....N. Cohen, '06.
Mar. 20, 1906.	"The Use of the Oscillograph for the Analysis of Alternating Current Wave-forms," L. A. Stenger, '06.
	"Automatic Sprinkler Systems as a Method of Fire Protection".....S. G. Harwood, '08.
	"Reinforced Concrete Water-tower,"..F. E. Wiesner, '06.
Apr. 25, 1906.	"Lightning Arresters,".....M. Cornelius, '06.
	"Application of the Cubic Parabola as an Easement Curve for Railways".....E. W. Kelley, '07.

Socially the Society has broken all precedent of former years. On the evening of Dec. 14th, 1905, about sixty members of the Society, including some members of the faculty, gathered together informally at the Varsity Lunch Room. Light refreshments were served after which impromptu talks were in order. F. E. Wiesner officiated as toastmaster and toasts were responded to by Dean Jones, Professors Flather, Haynes, Hoag, Bass, Kavanaugh, Kirchner for the faculty, and E. E. Adams, '06, and B. E. Smith, '07, for the Society.

On Saturday, May 19th, 1906, the annual banquet will be held at the East Side Commercial Club. It is expected that a large number of the members of the Society will be present and an enjoyable evening is anticipated.

May 10th, 1906.

UZZELL ALSOP BATSON HOPPIN MOWRY NEKOLA WIESNER ADAMS STEPHENSON BELL

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MODERN TENDENCIES IN THE UTILIZATION OF POWER.

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It has been stated that to the construction and perfection of her machinery, more than to any other cause, may be ascribed the present commercial supremacy of the United States.

Be that as it may, the economical production of her manufactures and the convenient adaptations of time and labor-saving devices in all the various lines of constructional work have certainly exerted a wonderful influence in the upbuilding of her industries.

Specialization in the manufacture of machine tools and labor-saving devices has followed closely the segregation of processes in other lines of industry, and thus there has been created a multitude of special machines, each designed to perform some single and often very simple operation.

Among other significant features the present tendency in the development and use of this class of machinery is marked by the adaptation of compresed air and the application of electric power to machine driving. In the use of compressed air, the facility of adaptation to various requirements which are in many cases additional to the supply of motive power, is a valuable feature peculiar to this system and one which is susceptible of extension along many lines.

The labor cost in most machine shops and other works is so

much greater than the cost of power, that any expedient by which the labor cost may be appreciably reduced is justified, even though the efficiency of the agent itself be low.

Engineers have recognized for some time past that there is a very great percentage of loss due to shaft friction, which, in railroad and other shops, where the buildings are more or less scattered, may be as great as 75% of the total power used. In the ordinary machine shop this loss will probably average from 30 to 50%.

In view of these facts we find a general tendency to introduce different methods by which a part of this loss may be obviated. Among these are the introduction of hollow and lighter shafting; higher speeds and lighter pulleys; roller bearings in shaft hangers; and the total or partial elimination of the shafting.

Independent motors are often employed to drive sections of shafting and isolated machines, and among these we find steam and gas engines, electric motors, compressed air and hydraulic motors, although the latter have not been used for this purpose to any great extent in this country.

More recently, the electric motor has superseded the steam engine for this work, as its economy and convenience over the latter is now thoroughly recognized.

The introduction of the electric motor in machine shops and factories was at first looked upon with disfavor and was opposed by many manufacturers, but the innovation obtained a foothold, and advantages which were at first unforseen were found to attend its use, so that now it is being very generally adopted for a wide variety of work.

A considerable difference of opinion exists as to whether individual motors should be used with each machine, or whether a number of machines should be arranged in a group and driven from a short line shaft.

There are well defined conditions to which each system is best adapted, but there are wide limits between which there appears to be no general rule and we find both methods occupying the same field.

For isolated machines and for heavy machines that may be in occasional use the individual motor is particularly well adapted, as it consumes power only when in operation. It is, however, necessary that each motor thus connected shall be capable of supplying sufficient power to operate its machine under the heaviest as well as lightest loads.

Fortunately, with electric motors the rated capacity is usually less than the safe maximum load, which is determined either by

the heating of the conductors tending to break down the insulation, or by excessive sparking at the brushes.

In many cases with individual motors, owing to wide variations in power required, the average efficiency of the motor may be very low; for this reason a careful consideration of the conditions governing each case indicates that for ordinary machine-driving, especially with small machines, short lengths of light shafting may be employed to good advantage and the various machines, arranged in groups, may be driven from one motor. By this method fewer motors are required and each may be so proportioned to the average load that it may run most of the time at its maximum efficiency.

When short lengths of shafting are employed the alignment of any section is very little affected by local settling of beams or columns, and since a relatively small amount of power is transmitted by each section, the shaft may be reduced in size, thus decreasing the friction loss. Moreover, with this arrangement, as also with the independent motor, the machinery may often be placed to better advantage in order to suit a given process of manufacture; shafts may be placed at any angle without the usual complicated and often unsatisfactory devices, and setting-up room may be provided in any suitable location as required, without carrying long lines of shafting through space. This is an important consideration, for not only is the running expense reduced thereby, but the clear head-room thus obtained can be more easily utilized for hoists and cranes, which have so largely come to be recognized as esential to economical manufacture.

As far as the efficiency of transmission is concerned it is doubtful whether in a large number of cases motor-driving *per se* is any more efficient than well-arranged engines and shafting.

The principal object to be kept in mind is a desired increase in efficiency of the shop plant in turning out product, with a reduction in the time and labor items, without especial reference to the fuel items involved in the power production.

One serious obstacle to the use of connected motors with machine tools is the difficulty of obtaining speed variation which is so necessary with a large proportion of the machines in common use.

In many of the larger sizes of metal cutting machine tools marked changes are already noticeable, and the indications are that direct connected motors with wide variations of speed and power will be incorporated in this class of machinery.

The recent improvements in the manufacture of certain grades of tool steel have shown indisputably that the present designs of machine tools are not sufficiently heavy to stand up to

the work in order to obtain the economy of operation which results from the use of such steels. Higher speeds, heavier cuts and greater feeds may be obtained if the machines will stand the strain, but in most cases the capacity of the machine is not commensurate with the ability of the tool to remove metal.

With cutting speeds of 100 to 200 ft. per minute, it is evident that the power requirements will be much greater than for the ordinary machines of today which have a cutting speed of from 10 to 30 ft. per minute.

Here, then, we find an interesting field for the direct connected motor with ample power and speed variation for any work which it may be called upon to perform.

Reference has been made to the use of compressed air and its facility of adaptation to various requirements, but it is evident from an inspection of some of the devices in use that enthusiasm for new methods rather than good judgment has controlled in many of its applications.

For some years compresed air was used only in mines where it produced marked economics in underground work. Later, compressed air was introduced into manufacturing lines and today its use in railroad and other machine shops, boiler shops, foundries and bridge works is being widely extended. In the Santa Fe railroad shops at Topeka there are over five miles of pipe in which compressed air is carried to the different machines and labor-saving appliances throughout the works.

New applications of compressed air are constantly being made, and each new use suggests another. This has a tendency to increase the number of appliances which are intended to be labor-saving devices, but in many cases the work could be done just as well and much more cheaply by hand.

A case in point is seen in an apparatus which was at one time in use on one of our prominent western railroads. It was a sort of portable crane hoist which could be fastened to the smoke-stack of a locomotive whereby one man could lift off the steam chest casing. The hoisting apparatus weighed about twice as much as the steam chest and took three men to put it up. When piece-work was adopted two men easily lifted off the steam chest and this "time and labor-saving device" was relegated to the scrap heap.

The success and economy which has attended the use of compressed air in so many lines of work has led to its adoption in fields which are much better covered by electrically operated machines. While compressed air has been used under certain conditions very satisfactorily to operate pumps and engines, printing presses, individual motors for lathes, planers, slotters, dynamos

and other work, it does not follow that it is always an economical agent under these various uses, or that other methods could not be used even more satisfactorily.

It has been proposed to use individual air motors in machine shops and do away with all line shafting, except possibly for some of the heavier machinery. This use of compressed air seems entirely outside the pale of its legitimate field; the general experience thus far indicates that rotary motors are not at all economical and generally are not as satisfactory as electric motors.

While the field is to some extent limited. yet the uses of compressed air are certainly not few. and in many lines of work marked economy results from its use.

The greater adaptability of compressed air to various purposes causes its use to increase along with that of the electric motor, for it has a different field of usefulness. independent of power transmission; at the same time when the requirements are properly observed in its production and use, its economy as a motive power in special cases compares favorably with other systems. With a better knowledge of the principles involved we may expect much better results than have yet been attained.

But compressed air possesses so many advantages that however inefficient it may be as a motive power its application to shop processes will be continually extended as its usefulness becomes better known.

In the transmission of air, within reasonable limits, the loss in transmission, if the pipes be tight, need not be considered, for although there is a slight loss in pressure due to the frictional resistances of the pipes, yet there is a corresponding increase in volum, due to drop in pressure, so that the loss is practically inappreciable.

There should be no comparison between the cost of power by compressed air and its brilliant rival, electricity, since each has its own field of usefulness.

Where cheap fuel is available it is found in most cases that electric power can be generated at the works more cheaply than it can be purchased from a central station; especially is this the case if the exhaust steam be used for heating purposes. In isolated plants the cost of transmission is very small as compared with the total cost of generation; whereas, in the average central station the cost of transmission, which includes interest and depreciation on pole line, usually constitutes a large percentage of the operating cost.

In those localities where the cost of fuel is high, electric power can often be purchased more cheaply from a central station, which obtains its power many miles distant and transmits it electrically

to a convenient distributing center where it is used for power and light.

The possibility of electrical transmision thus permits of the utilization of available sources of power at great distances from the center of distribution; but while it is interesting to know that a certain amount of power may be transmitted a given distance with a high degree of efficiency, it is more important to know whether the same amount of power could be obtained at the objective point more economically by other means.

It has been suggested that the future of long distance transmission depends largely upon the development of oil as a fuel; but at the present time the outlook for oil fuel in general competition with coal or long distance transmission is not encouraging; while the development of the Texas and Southern California oil fields has increased the available supply and brought about increased activity in the use of liquid fuel yet it is doubtful whether the advantages would be sufficient to cause it to come into general use as a fuel, since with a limited production and an increased demand for this and other purposes the cost would be correspondingly increased.

A number of railroads contiguous to the oil producing centers have equipped their locomotives to burn this fuel, and it is used to some extent to fire marine boilers; very satisfactorily, too, since its displacement for a given heating value is only about one-half that of coal, and the labor cost is materially reduced. It is also used quite extensively in certain sections of the country as a steam producer in power plants, but it is hardly probable that liquid fuel will be a serious competitor of coal, notwithstanding its many advantages.

At the present time, as far as power for manufacturing plants is concerned, it is largely a question of transportation, whether oil can be laid down and handled at a given point more cheaply than coal. It is probable, however, that oil fuel will supply a local demand in certain sections where transportation charges will permit its use at a low cost, and it is in this connection that it may become a competitor of electrical transmision.

One interesting phase of the power problem which forcibly presents itself to the engineer at the present time is the vast possibilities possessed by the modern combustion engine, which includes the various types of gas and oil engines. While its use as a motor in industrial establishments has been somewhat limited, yet there is a marked tendency to employ the gas engine in manufacturing works, and a consideration of its advantages and cost of operation, together with its high thermal efficiency and possibility of still further improvement, indicates that for a great

many purposes both steam engines and electric motors may be ultimately replaced by combustion engines.

That the gas engine in both large and small sizes has reached a point in its development where it can fairly rival the steam engine in reliability and satisfactory running qualities there can be no question. In point of fuel economy, a gas engine of moderate size is on a parity with the largest triple expansion steam engines.

The high price of gas in this country has contributed largely to those causes which have prevented a more common use of the gas engine as a motor. For this reason the gas engine has generally been used, not so much because of its high efficiency as a thermodynamic machine, but rather on acount of its convenience and saving in labor. It is true that natural gas is cheap, but it is equally true that natural gas is not generally available.

It is to producer gas that we must look for any marked increase in the use of the gas engine. Fortunately the manufacture of producer gas has reached a high state of development and there are now in successful use several processes by which power gas can be made from cheap bituminous coals as well as anthracite and coke. The results of the government tests at St. Louis indicate that lignite is a particularly valuable fuel for this purpose and a number of manufacturers are now giving their attention to its development. The low heating values of all producer gases render them less effective per cubic foot of gas, as compared with the richer coal gas or even water gas; but this difference is more than compensated for by the low cost of production. It is upon such power gas that the commercial future of the gas engine as a general motor depends.

The producers are very simple in operation and furnish a convenient and economical means of obtaining power at a much lower rate than with the ordinary city lighting gas. With bituminous coal, means must be provided for removing the tar and ammonia, and other products of distillation, but with large plants the recovery of such by-products may be made remunerative. With small plants anthracite, charcoal or coke give the better results and are generally employed.

The gas engine industry made rapid advancement when it was discovered that blast furnace gases could be readily utilized direct in combustion engines without the intervention of boilers and without any special purifying processes. Still more important is the fact, shown by Prof. Hubert, of the Liege School of Mines, that the superior economy of the gas engine enables equal power to be obtained with 20% less consumption of furnace gas than was formerly used in the generation of steam.

The successful employment of large combustion engines in

this way utilizes vast sources of power which a few years ago were allowed to go to waste or at most were used very ineffectively.

An important question now before the American public, closely related to the problems of power development, is the manufacture and free importation of denatured alcohol. Aside from the vast possibilities of this agent in the arts and manufacturing industries the special field of power production in itself is sufficient to demand that it be not restricted by taxation. It has been shown that a cheap alcohol even if it contains as much as 15% of water, is an excellent fuel for combustion engines, as there is little danger from pre-ignition under high compression so that very high efficiencies may be obtained; an additional advantage is the freedom from disagreeable odors which are often associated with other combustion engines. There is lacking, then, only low prices to render this fuel a formidable competitor of gasolene and other gas engine fuels. Alcohol made from sugar cane refuse can be purchased today in Cuba at from seven cents to ten cents per gallon, but the duty on this is $2.75 per gallon! A good quality of alcohol, suitable for this purpose, can be made from the waste beet pulp of our sugar factories, but the tax on this is prohibitive at the present time. Should this tax be removed the manufacture and use of power motors of the smaller class would receive a signal impetus which would be far reaching in its effect.

The high thermal efficiency of the gas engine has long been recognized and the possibility of further development is a promising factor in this field. Efficiencies of 30% or more have been obtained with blast furnace gases which contain a very small percentage of hydrogen, and this with the high rates of compression which can be carried has led to the advocacy of non-hydrogenous mixtures in large engines. Certainly very high rates of compression may be had with a non-hydrogenous producer gas without fear of premature ignition, and it has the additional advantage of economical production.

Very satisfactory results have recently been obtained in the construction of 2-cycle engines. In some of these we find separate pumps employed to compress the charge of gas and air, which ignites and burns as it enters the cylinder. Higher compression is thus obtained without fear of pre-ignition and this permits smaller clearance spaces with attendant advantages.

The highest thermal efficiency yet attained; namely, 38%, has been secured with a 2-cycle type of engine, but whether these engines will be as satisfactory for small motors remains to be seen. It is possible that the greater complication of details

in the 2-cycle types as compared with the simpler 4-cycle engine will cause the latter to continue to give the greater satisfaction, at least for the smaller sizes; for, notwithstanding the well-known defects of the 4-cycle engine this type constitutes by far the largest class of successful gas engines in use today.

Although this country has been somewhat slow in adopting large gas engines, there is evidence that this state of affairs will not exist very long, since a number of enterprising firms are already in the field prepared to build gas engines up to any required size. One firm has already sold over 40,000 H.P. of large engines, most of them of 2,000 H.P. and several of 1,000 H.P. for coupling to electrical generators.

The use to which these large engines are put is about equally divided between the operation of blowing engines for blast furnaces and the driving of dynamos for general power distribution.

While the gas engine in the larger sizes is thus used extensively for the generation of electric light and power a growing tendency is observed to use it direct as a motor.

A number of railroad and other machine shops have been equipped with small gas engines suitably located about the works, and in addition, thousands of horsepower are used in the smaller sizes for a wide variety of purposes, including village water works, isolated lighting stations, and manufacturing plants of all kinds.

It is not to be understood that the gas engine will displace either the electric motor or the steam engine; each has its legitimate sphere of usefulness, and each will be more highly developed as the result of direct competition. Yet the economies already obtained indicate that the field of the gas engine will be extended more and more into that of the steam engine and the electric motor.

Many of the questions involved in this consideration are at the present time in a transitional stage. The reciprocating steam engine has reached a high stage of development, but it is not probable that it has attained its highest degree of perfection. While an economy less than 9½ lbs. of steam per horse power has been obtained, even better results may be anticipated; the use of high pressure superheated steam in compound, jacketed engines involves more perfect lubrication and this may demand modification in existing valve types; however this may be, the outlook is promising for still higher effciencies; whether this will mean cheaper power than can be obtained in other ways will depend upon many conditions.

In any case, and especially with intermittent or variable loads, it is not so much a question of maximum efficiency as it is economy of operation.

From this point of view the present activity in the construction and development of the steam turbine is of interest to engineers and power users. The steam consumption of a modern steam turbine of moderate size compares very favorably with that of the better class of large reciprocating engines, but what is of greater importance is the evident superior steam economy under variable loads. The steam consumption per horse power varies little from one-third to full load; at over-loads the economy, as shown by numerous tests, may be even better.

This feature predestines the steam turbine to the special field of electric lighting and power generation, where it must inevitably become a formidable rival of the larger sized slow speed reciprocating steam engine.

The high rotative speed of the steam turbine is a prominent factor in favor of its adoption in connection with electrical generators, since the cost of the generator and of the equipment ought eventually to be very materially reduced; but for many lines of work the high rotative speed of the present types of steam turbine is prohibitive, nor can it be adapted successfully to belt driving. However it is fair, to presume that the present limitations of the steam turbine are not insuperable, and that the attention which is now being given to its development will evolve a more universal type of motor adapted to general power purposes with large and small units alike.

It has recently been pointed out that the most economical and reliable plant for large electrical installations is the combination of steam turbines and gas engines. Such a plant suggests a very attractive proposition and according to Mr. Stott*, offers a possibility of producing a kilowatt hour for less than one-half of its present cost. Whether this can be attained is doubtful, but certainly marked economics would result from such combination owing to the utilization of the gas engine wastes; moreover, the overload possibilities due to the flexibility of the steam turbine is a very desirable factor, not possessed by the gas engine if used alone.

The economies already obtained with both the steam turbine and the gas engine have brought each into a prominence, which is at least suggestive of the important developments that are taking place in methods of obtaining and using power.

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*(Proc. A. I. E. E., January, 1906.)

THE JUSTIFICATION OF THE USE OF THE EXPRESSION "ENGINEERING MATHEMATICS."

PROFESSOR A. E. HAYNES.

Being invited to write briefly on the above topic, I gladly do so, because, as far as I am aware, the expression originated in the University of Minnesota, in January, 1901, when the writer, with the approval of the president of the university, changed the name of the professorship he occupied from the professorship of mathematics in the College of Engineering to the professorship of Engineering Mathematics.

The reasons for the use of this expression are at least three.

First: Because of the main object of the study of mathematics in an engineering course. In a purely disciplinary or academic course the objects of the study are first mental discipline and second its practical use, while in a professional course in engineering these two objects are reversed in relative importance; in other words, the primary object in such a course is to so master the subject as to be able to make a correct and intelligent use of its principles and formulas in practice. In other words, these principles and formulas are to be used as "tools" (I think this expression was also first used in this university)*, by which, like as the student uses a plane or any other tool of the shop, he may secure desired results.

Incidentally, in mastering the logic involved, the student gets excellent mental discipline, but there is added to this a still greater discipline and a commendable inspiration in applying his knowledge so as to get direct practical results.

There is, to be sure, some valuable discipline in so studying a jack-plane as to understand its construction completely, but one can do all this without being able to properly plane a board.

Just so one may, for instance, be able to develop a mathematical principle or formula without being able to use it intelligently in securing results.

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*See Vol. VIII., pp. 308 and 310, Proceedings of the Society for the Promotion of Engineering Education.

P.S.—I think the use of the terms Engineering Drawing, Engineering Physics, etc., equally justifiable. —A. E. H.

Another example is ventured for illustration; in Physics, where the members of the class are simply studying for the knowledge alone, and not for the object of applying such knowledge, they may completely understand the philosophy, for instance, of the sextant, and yet be perfectly helpless when required to find the angular distance between two objects by means of its use.

In fact, in the study of the mathematics of an engineering course, the student must constantly challenge principles and formulas with the question, what use has this in practical application to my chosen profession?

In Truth—Three questions are constantly pressing upon both the student of engineering and the professional engineer for an affirmative answer; they are: What do I want? Do I know how to secure it? Do I know how to use it intelligently and correctly?

Suppose, for example, he finds it necessary to solve a problem in trigonometry, he may have to answer these questions repeatedly, as in determining the proper formulas, and in correctly selecting and applying them; again, in the same problem, the determining whether to use natural or logarithmic functions and the proper selection and correct use of them. And thus, it comes about, in the study of mathematics for engineering purposes, that the main object sought fixes or shapes the method of study. But this leads naturally to another reason for the justification of the expression and that is;

Second: Because such an object requires a different kind of teaching. Some one has recently said: "In almost every branch of instruction there is a gap between theory and practice, between principle and application. In nothing is this more manifest than in the teaching of mathematics."

As has been already indicated, one may, by mastering a mathematical principle, secure valuable mental discipline; but if the teacher makes this the primary or chief object, he will not teach the subject with the success that he would have, by having constantly before him the thought that skill in the intelligent use of mathematics, in practice, is the main end to be attained.

And so, the question may here be legitimately asked, will the teacher, untrained in engineering practice, or not educated as an engineer, be as likely to succeed in such teaching as one who is so trained or educated? I think this question must be, in general, answered in the negative.

Such teaching requires, on the part of the teacher, that he be able to intelligently direct the student in his study, that he have the ability and good judgment to select problems that shall wisely lead the student to a correct and practical application of

his knowledge, and above all, that he possess the power of constantly inspiring the pupil by high ideals of work and of life.

But, if the object sought shapes both the method of study and of the teaching of the subject, it leads directly and logically to still another reason for the justification of the expression, and so, we have

Third: Because the content or extent of the field covered is different.

For example, long and abstruse discussions of principles and formulas, the object of which is mostly mental discipline and which have little or no direct practical value are omitted, while subjects, not found in former treatises are added.

A good illustration of this is seen in introducing the philosophy and use of the *slide rule*, after the theory and use of ordinary logarithms have been properly considered.

The student is thus lead to the intelligent comprehension and use of one of the most valuable aids in modern engineering practice.

And again, after a study of the theory of ordinary integration, the study and use of the polar planimeter or mechanical integrator adds great interest and value to the student's work.

In conclusion, it may be said that in consequence of the three reasons given in this paper for the justification of the term "Engineering Mathematics," great and valuable changes have been made, during the last decade especially, in text books in mathematics for engineering students, and we may ultimately expect nothing further to be desired in such works.

January, 1906.

INDUCTION BETWEEN TWO PARALLEL WIRES.

GEORGE D. SHEPARDSON.

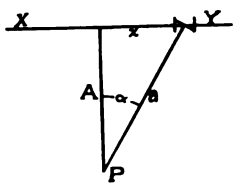
(A) *Self induction of two parallel wires.*

The coefficient of self induction of any circuit equals the number of turns or loops of the conductor multiplied by the number of lines of force included divided by the current in the conductor causing the magnetic flux. Using CGS units, we have

$$L = \frac{N\,\emptyset}{I}.$$

In the case of parallel wires, $N = 1$, and $L = \frac{\emptyset}{I}$. The flux is partly between the conductors and partly within one or the other.

The CGS unit current is a current of such strength that, when flowing through a wire at right angles to a magnetic field of unit intensity, each centimeter of the wire is pushed sidewise with a force of one dyne. In any direction from a magnet pole of strength m in a medium of unit permeability the field is $f = m/D^2$. The force between a magnet pole and a current in a wire in its vicinity varies with the distance, and the total force is the summation of the various elements.



The force between a unit magnet pole P and any element dx of the wire XY carrying current I is the product of current by the projection of the element of wire in the direction of the magnet, divided by the square of the distance a from the element to the magnet. The total force F is the summation of all the elements from one end to the other, the angle subtended by any element varying from $+\pi/2$ to $-\pi/2$. Thus,

$$dF = \frac{I\,dx\cos a}{a^2} = \frac{I\,A\sec^2 a\,da\cos a}{A^2/\cos^2 a} = \frac{I\cos a\,da}{A};$$

for $x = A\tan a$; $dx = A\sec^2 a\,da$; $A/a = \cos a$; $a^2 = \frac{A^2}{\cos^2 a}$;

$$\sec a = \frac{I}{\cos a} \quad \therefore F = \int_{-\pi/2}^{+\pi/2} I/A \cos a \, da = I/A \sin a \Big\{ \begin{matrix} +\pi/2 \\ -\pi/2 \end{matrix} = \frac{2I}{A}.$$

which is Biot and Savart's law (Ann. Chim. Phys. 15: 222, 1820) for the field strength at distance A from a long conductor.

The work done in carrying a unit magnetic pole around the wire is the product of force by distance, or

$$W = 2\pi AF = 2\pi A \, 2I/A = 4\pi I$$

and is therefore independent of the path taken, since A eliminates.

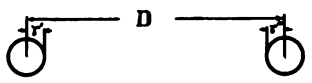
The magnetic induction in a medium of permeability μ is

$$B = F\mu = 2I\mu/A.$$

The flux through a space of unit width and of radial depth dA is

$$B_A \, dA = d\emptyset_A = 2I\mu \, dA/A.$$

The total flux through the space between the surface of one wire and the center of the second wire, due to current in the first wire is



$$\emptyset' = \int_r^D 2I'\mu \, dA/A = 2I'\mu \log_e D/r$$

in which r is the radius of the wire and D is distance between centers. The effect of the permeability of the second wire is negligible, since it usually constitutes but a negligible portion of the path of the flux due to the first wire.

The current in the second wire will send through the same space,

$$\emptyset'' = 2I''\mu \log_e D/r''.$$

Within the wire at any distance b from the center, the magnetic effect is as though the current within radius b were concentrated at the center. The combined magnetic effects of the current elements at radii greater than b are neutral for all points within b. For, consider the conductor as divided into two concentric cylinders divided at radius equal to b, and divide the outer cylinder into a series of pyramids with apices at any point inside; the force due to the element of current in each small pyramidal section is $F = 2i/a$, in which i is the element of current, and a is the distance from the point; the area of each element is proportional to the distance from a, and the current is like-

wise, assuming that the current is symmetrically distributed in any concentric layer of the cylinder; therefore the force of each element of current upon a point within is exactly neutralized by that from its complimentary element.

The strength of field at any point b within the wire is therefore

$$F_b = \frac{2I}{b}\,\frac{\pi b^2}{\pi r^2} = \frac{2Ib}{r^2}$$

and the magnetic induction at b is $B_b = \dfrac{2\,I\,\mu' b}{r^2}$

The total flux through a rectangle of unit length and radial breadth db is $\emptyset_b = B_b\,db = 2\,I\,\mu'\,b\,db\,/\,r^2$

This flux is linked not with all the current, but only with that within a cylinder of radius b, or with

$$I_b = I\,\frac{\pi b^2}{\pi r^2} = I\,\frac{b^2}{r^2};$$

and the current flux linkage is

$$I_b\,\emptyset_b = I\,b^2/r^2\,2I\,\mu'\,b/r^2\,db = 2I^2\,\mu'\,b^3\,db\,/\,r^4.$$

The total flux linkage within the wire is

$$I_1\,\emptyset_1 = \int_0^r 2\,I^2\,\mu'\,b^3 db/r^4 = 2\,I^2\,\mu'/r^4\;\; b^4/4 \Big\}_0^r = I^2\,\mu'/2,$$

or, the effective flux is $\emptyset_1 = I\,\mu'/2$.

The total internal and external flux due to one wire is therefore,

$$\emptyset' = \emptyset'_x + \emptyset'_i = 2\mu I' \log_e D/r' + I'\mu'/2 = I'\,(2\mu \log_e D/r' + \mu'/2).$$

Similarly, the flux due to the second wire is

$$\emptyset'' = I''(2\mu \log_e D/r'' + \mu''/2).$$

The total flux linkage of the circuit is the sum of the two.

$$\emptyset = I'\,(2\mu \log_e D/r' + \mu'/2) + I''(2\mu \log_e D/r'' + \mu''/2).$$

For copper or aluminum wires in air, $\mu = 1$, $\mu' = \mu'' = 1$, and

$$\emptyset = I'\,(2 \log_e D/r' + 0.5) + I''(2\mu \log_e D/r'' + 0.5).$$

For iron conductors, μ' and μ'' are often taken as 150 to 200.

When the conductors are of the same size and material, and when the currents in the two conductors are equal, the formula becomes

$$\emptyset = 2\,I\,(2 \log_e D/r + 0.5)$$

Then, since $L = N\emptyset \div I$, we have

$$L = 2\,(2\mu \log_e D/r + \mu'/2) = 4\mu \log_e D/r + \mu' =$$
$$4\mu\;2.3 \log_{10} D/r + \mu' = 9.2\mu \log_e D/r + \mu'.$$

For aerial copper or aluminum wires, the self induction of the loop or pair of wires is

$L = (1 + 9.21 \log D/r)\ 10^{-6}$ millihenries per centimeter.
$= 2.54 \times 1000\ (1+9.21 \log D/r)\ 10^{-6} = .03048 + .281 \log D/r$ millihenries per 1000 feet.
$= .161 + 1.482 \log D/r$ millihenries per mile.

For a grounded single wire circuit, the earth is considered as a sheet conductor spread over the earth's surface and equivalent to a cylindrical return conductor, or "image" at a distance below the surface of the earth equal to the height of the aerial conductor above it. The general equation then becomes

$$L = 4\mu \log_e 2H/r + \mu' = 1 + 9.21 \log_{10} 2H/r$$

in which H is the height of wire above ground. The current actually goes deeper than the hypothetical sheet, consequently the formula gives the minimum value.

(B) *Mutual induction between parallel wires.*

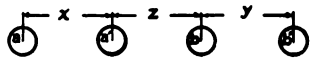
The coefficient of mutual induction between two circuits is equal to the number of turns of the second circuit multiplied by the number of lines of force passing through the second circuit due to unit current in the first circuit.

$$E'' = n'' \frac{d\emptyset}{dt} = n'' \frac{d}{dt}\left(4\pi n' I' \frac{A\mu}{l}\right) = 4\pi n' n'' \frac{A\mu}{l} \frac{dI'}{dt} = M \frac{dI}{dt}.$$

$4\pi n' A\mu/l$ is the number of lines of force through secondary when primary current is one CGS unit.
$4\pi n^2 A\mu/l$ is the CGS coefficient of self induction of primary.
$4\pi n' n'' A\mu/l = CGS$ coefficient of mutual induction, which is to be multiplied by 10^9 to equal practical units.

In the case of parallel conductors such as on a pole line or cable, $n' = n'' = 1$ and ordinarily, $\mu = 1$.

The mutual inductance between parallel conductors of great length may be calculated easily if dimensions are known, by extending the methods of determining self-induction so as to determine the net number of lines included by the second circuit.

Case 1. 

For all practical cases, the current may be considered as concentrated at the center of each wire, since the diameter of wire is small compared with distances between.

The lines included by unit length of circuit bb' due to unit current in a' are

$$\emptyset a' = \int_{z}^{y+z} 2\, da/a = 2 \log_e (y+z) - z$$

the lines due to current in a are in opposite direction, as current is so,

$$\emptyset a = - \int_{x+z}^{x+y+z} 2 da/a = -2 \log_e (x+y+z) \div (x+z)$$

The mutual induction between the two circuits per unit length is in CGS units:

$$M = \frac{n''\emptyset}{I'} = \emptyset'' = \emptyset a' + \emptyset a = 2 \log_e \frac{y+z}{z} - 2 \log_e \frac{x+y+z}{x+z}$$

$$M = 2 \log_e \frac{(x+z)\ (y+z)}{z(x+y+z)}$$

When $x = y$, as is usually the case on four-pin crossarms, it becomes

$$M = 2 \log_e \frac{(x+z)^2}{z(2x+z)} = 4.6 \log_{10} \frac{(x+z)^2}{z(2x+z)} \text{ CGS.}$$

$$= (4.6 \div 10^9) \left(\log_{10} \frac{(x+z)^2}{z(2x+z)}\right) \text{ henry per cm. length loop.}$$

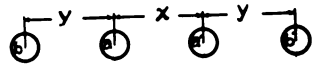
$$= .00014 \left(\log_{10} \frac{(x+z)^2}{z(2x+z)}\right) \text{ henry per 1000 feet}$$

$$= .000741 \left(\log_{10} \frac{(x+z)^2}{z(2x+z)}\right) \text{ henry per mile.}$$

When $x = y = z$, as in the case of long crossarms with many pins,

$M = 2 \log_e 4/3 = 4.6 \log_{10} 1.33 = .574128$ CGS per centimeter length.

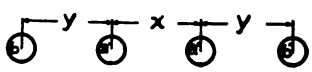
Case 2.



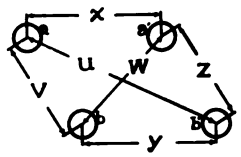
The flux between a-a' due to $a+a'$ is $\emptyset = 4 \log_e x/r$.
The flux between a-b due to a is $2 \log y/r$.
The flux between a-b due to a' is $2 \log (x+y)/x$.
The flux between a-b due to $a+a'$ is $2 \log y/r - 2 \log (x+y)/x$.
$= 2 \log xy/r(x+y)$.

Similarly, flux through a'—b' is an equal quantity by symmetry. The total flux through b—b' is

$$M=\emptyset=4\log_e x/r-4\log_e\frac{xy}{r(x+y)}=4\log_e\frac{r.r(x+y)}{rxy}=4\log_e\frac{x+y}{y}.$$

Case 3. 

Reduces to same as case 2.

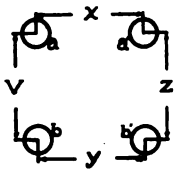
Case 4. 

When wires are not in same plane;

$\emptyset$ in b—b' due to $a=2\log u/r-2\log v/r=2\log u/v$;
$\emptyset$ in b—b' due to $a'=-(2\log z/r-2\log w/r)=-2\log z/w$
$=2\log w/z$;
Total $\emptyset$ in b—b' due to a—$a'=2\log u/v-2\log z/w=$
$=2\log uw/vz$.

Case 5.

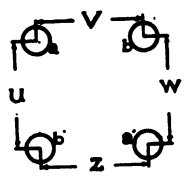
When one circuit is directly under the other, $x=y$; $v=z$; $w=u=\frac{1}{2}(x^2+z^2)/z^2$ and the formula becomes—



$M=\emptyset=2\log uw/vz=2\log w^2/z^2=2\log(x^2+z^2)/z^2$ CGS =
= .0000000046 $\log(x^2+z^2)/z^2$ henry per centimeter. ... ...
= .00014 $\log(x^2+z^2)/z^2$ henry per 1000 feet.
= .000741 $\log(x^2+z^2)/z^2$ henry per mile.
henry per centimeter.
When $x=y=v=z$, $\emptyset=2\log 2=4.6\log_{10}2=1.38$ CGS per cm.

Case 6.

When $v=z$; $u=w$; $x=y$;
$\emptyset$ in b—b' due to a is $2\log v/u$;
$\emptyset$ in b—b' due to a' is $-2\log w/z$
Total $\emptyset$ in b—b' is $2\log v/u-2\log w/z$
$=2\log zv/uw=O$;
Therefore $M=O$.



By transposing b and b' midway between each two points where the current changes value, the value of M in any of the above cases, becomes zero.

For any combination of the conductors, the mutual induction

is neutralized by such a system of transposition that the relative positions of each pair to every other are transposed.

The above discussion of mutual induction follows closely that given by Jackson in "Alternating Currents and Alternating Current Machinery," pages 397 to 404 and 421 to 425.

Examples of transpositions to avoid mutual inductance may be found in Carty's paper in Transactions American Institute of Electrical Engineers, Vol. 8, page 100; Hopkins' "Telephone Lines," pages 196 to 201; Miller's "American Telephone Practice," page 387; Foster's "Electrical Engineer's Pocket Book," pages 116 to 121; Dobbs' paper in New York Electrical Review, Vol. 39, pages 760 to 789; Fowle's paper in Transactions American Institute of Electrical Engineers, Vol. 23, page 659.

(C) *Self induction of a three-wire three-phase circuit.*

In a three phase circuit with wires at the apices of an equilateral triangle, two wires may be considered as the return for the other. The self induction between two wires may be considered, since the magnetic flux due to the third wire passes both in and out of the space between the other two, and therefore has no effect upon them.

The current at any instant in wire A is $I\text{m} \sin \omega t$, while that in wire B is $I\text{m} \sin (\omega t - 120°)$. The flux between the two wires at any instant is therefore

$$\begin{aligned}\emptyset_{AB} &= I\text{m} \sin \omega t (2\log_e D/r + .5) + I\text{m} \sin(\omega t - 120°) \quad (2\log_e D/r + .5) \\ &= I\text{m} (4.6 \log_{10} D/r + .5)(\sin \omega t + \sin (\omega t - 120°)) \\ &= I\text{m} (4.6 \log D/r + .5) \sqrt{3} (\sin(\omega t + 30°))\end{aligned}$$

For the resultant of two currents 120° apart is, as shown later,

$$2(I\text{m} \cos 30°) = 2 \times .866\, I\text{m} = \sqrt{3}\, I\text{m}.$$

The maximum flux is $\emptyset_{AB} = \sqrt{3}\, I\text{m}\ (4.6 \log D/r + .5)$,
and the mean flux is

$$\emptyset_{AB} = \sqrt{3}\, \text{I}\ (4.6 \log D/r + .5) = \text{I}\ (7.97 \log D/r + .866).$$

The self induction of the loop AB is

$$L_{AB} = \emptyset_{AB} \div \text{I} = \sqrt{3}\ (4.6 \log D/r + .5)$$

in CGS units per centimeter length of loop.
The self induction of one wire is that of the loop divided by $\sqrt{3}$.

When the three wires are on one cross arm, equally spaced and transposed so that each wire occupies each position for one-third the distance, one wire will have no net effect upon the loop between the other two. The self induction of a loop is then, for length of the line d, and with distance D between adjacent wires,

$$L = \sqrt{3}\ (4.6 \log D/r + .5)\, 2/3\, d + \sqrt{3}\ (4.6 \log 2/Dr + .5)\, d/3.$$

Multiply any of the above formulæ by 2.54 x 12 x 1000 x 10^{-9} = 30.48 x 10^{-6} to reduce to millihenries per 1000 feet, or by 30.48 x 5.28 x 10^{-6} = 161. x 10^{-6} for millihenries per mile.

(D) *Drop in three-phase lines.*

In a three-phase transmission line, the instantaneous sum of the currents in the three conductors is zero, if all are considered with reference to the direction of the line; for there is no storage of electricity, and the sum of the currents in two of the wires at any instant must equal that in the other wire.

There are two methods of connecting generating or translating devices for three-phase operation; the "delta," mesh, or triangle method and the "Y", or star method. When the three legs of a generator or load are connected in "Y," the current in the line is the same as that in a leg; and the EMF between two line wires (neglecting any change of voltage by raising or lowering transformers) is the vector sum of the EMFs in the two legs of the generator or load. When the three legs of the generator or load are delta-connected, the EMF between two line wires equals that in one leg, but the line current is the vector sum of the currents in two legs of the generator or load. The Y-connection is adapted to the generation and utilization of high potential energy, since the EMF in any one coil is less than that on the line, making insulation less difficult. The delta connection is suitable for low voltage heavy current work, and also for double-current machines and rotary converters. For step-down or step-up transformers, the delta connection has the advantage that in case of breakdown of one transformer, the other two can carry two-thirds of the load. Two delta-connected transformers are sufficient for small motor or other loads, although such practice makes the current in the common wire greater than in either of the other two, introducing an unbalanced load which generally may be corrected by properly coupling other loads.

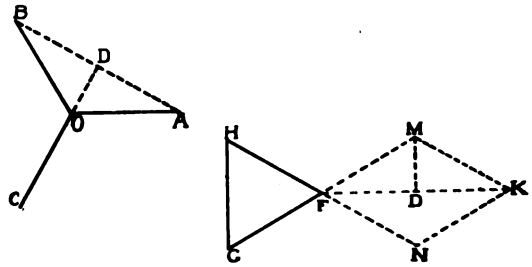
When the circuits are balanced, i.e., with equal current and potential in each leg, the EMF between two outer wires is $\sqrt{3}$ times the EMF in either leg of a Y-connected generator or receiver. Likewise, in a balanced delta system the current in a line wire is $\sqrt{3}$ times the current in any leg of generator or receiver.

For if the figure at the left represents three EMFs 120° apart, the resultant of any two, such as OA and OB is

$$AB=AD+DB=OA\cos 30^\circ+OB\cos 30^\circ=2OA\cos 30^\circ=\sqrt{3}OA$$

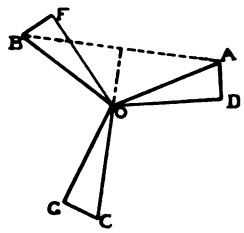
Likewise if the figure at the right represents three currents, 120° apart, the resultant of HF and GF, 120° apart is

$$FK=FD+DK=FM\cos 30°+MK\cos 30°=$$
$$FG\cos 30°+FH\cos 30°=$$
$$=2\ FG\cos 30°=\sqrt{3}\ FG.$$



The line drop in a loop of a three-phase circuit is the resultant of the ohmic and reactance drops in each of the two wires of the loop.

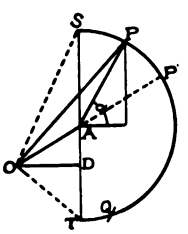
Let OD be ohmic drop and DA reactive drop in wire A.
Let OF be ohmic drop and FB reactive drop in wire B.
Let OG be ohmic drop and GC reactive drop in wire C.



Then OA, OB and OC are the impedance drops in the respective wires. The drop in the loop AB is thus the vector sum of the two drops. If the circuit is symmetrical and equally loaded, OD=OF=OG; DA=FB=GC; OA=OB=OC; and, AB=BC=CA=OA cos OAB + OB cos OBA=OA $\sqrt{3}$.

The generator EMF required to deliver a required receiver voltage over a line of known resistance and reactance (or, the difference between generator and receiver voltage) depends upon the power factor of the load. A Y-connected generator and a Y-connected load may be taken as the simplest case, considering each leg of the circuit as completed by a hypothetical neutral wire.

In the figure let OD represent the drop deu to line resistance DA drop to line reactance, AP the voltage at receiver. The angle a between the receiver voltage and current will depend upon the power factor of the load, with a theoretically possible variation from 90° lag at AS to 90° lad at AT. The generator EMF, which equals the resultant of line drop and receiver voltage, may therefore vary from OS to OT, being a maximum at OP' when OA and AP lie in the same straight line, i.e., when the power factors or time constants of line and load are equal.



When the reactance of line and load are of opposite sign and of certain relative values, the generator EMF may be equal to or less than the voltage at the receiver; for example, OQ equals AP, OT is less than AP.

Having determined the required EMF in one leg of the Y-connected generator as above outline, the EMF between two line wires at the generator end may be determined by the vector addition of the EMFs of two legs of the generator as outlined above. When the line is symmetrical and the load is balanced, the EMF between two line wires is $\sqrt{3}$ times the EMF of one leg of generator or receiver respectively.

When the generator or load is delta connected, AP and OP may be considered as the voltages between the real terminals and the centers of hypothetical or real circuits, each consisting of three resistances Y-connected to the three line terminals; the EMF required for each leg of the delta connected generator is then $\sqrt{3}$ times that thus determined.

INSTRUCTIONS TO ASSISTANT ENGINEERS FOR YARD SURVEYS BY GREAT NORTHERN RAILWAY LINE.

F. B. WALKER, C. E.,
Minn., '97.

All surveys must be connected with the original location numbers, which can be picked up from the intersection of the nearest curve, if possible. If not possible to pick up curve intersection, take some equally good permanent point. Preserve the original station numbers for P.C's and P.T's, and record any difference in angle, degree of curvature or length of tangents. Long or short stations should be established outside station grounds wherever practicable, but always on the tangent where they occur.

Section Lines.—All section lines crossing the yards should be correctly located by running a straight line between the nearest section or quarter section corner on each side of the yards, noting the distance to each corner, angle and station of intersection with main line.

Buildings.—All buildings inside or in immediate vicinity of the R.W. Give accurate location, size, whether frame or brick, for what used, and where not the company's property, give owners' names. This record must include platforms, giving size, location, height above rail and material of which they are built. In locating a building parallel with main track, a station number at east end and distance from center of main track to side of building, and size of building is all that is required. Where buildings are not located parallel with main track, location should be given from two points in main track, as per sketch.

Give distance to two corners from one point and to one corner from the other point. Buildings can then be platted correctly on maps..

A ground plan sketch should be taken of depot, showing size and location of each room, location of doors and windows, also sketch of stock yards, showing pens, sheds, alleys, chutes, gates, scales, well, etc., and the manner of construction. Regular blanks are furnished for side tracks, buildings, depots and stock

yards should be used in all cases, and care taken to see that all information called for on the blanks is furnished.

Fences, Telegraph and Telephone Line.—All fences, telegraph and telephone lines inside of, adjoining or in immediate vicinity of Railway. Give location, kind and owners' names.

Road Crossings.—Give accurate location; state whether public or private and if planked. If private, give name of party for whose use constructed.

Roads.—All roads inside of or in immediate vicinity of railway. Give accurate location and state whether public or private.

Bridges, Culverts and Drainage Ditches.—Give location, kind and size, and designate the outlet end of culverts. This should include all within at least 1,000' outside headblocks.

Cattle Guards.—Give location and state if pit or surface.

Sign Boards.—This includes road crossing, station and warning signs, mile and flanger posts, etc. Give location and description.

Sidings, Spurs, Etc.—All sidings, spurs, etc., to be located by offset measurements taken sufficiently close that the plat can be made to show the tracks as they actually exist. Give kind of switch, number of frog and weight of rail; and accurate location of headblock, and point of frog. If headblocks have been changed since last survey, make special note of this fact. Where spur tracks are partly outside of right of way it is necessary to get the amount of track off of right of way separate, as question of ownership may come up.

Pipe Lines.—Give accurate location and state kind, length and diameter of pipe.

Streams.—Give accurate location of all streams inside of or in immediate vicinity of railway.

Townsites and Additions.—Careful and sufficient ties should be made to all recorded, surveyed sub-divisions of property within the boundaries of the station ground map to enable the office to show same correctly on the maps. All points tied in should be described, whether post, hub, stone or iron monuments. A copy of each recorded plat tied to should be borrowed, or if more convenient, traced directly from the records of the county seat at which it is filed, and forwarded with your notes to the office to be used in preparing the station ground maps.

Miscellaneous.—Give location, description and owners' names of all other improvements of whatever nature within or near railway. Also give accurate location of bench mark monuments established by the United States Geological Survey, wherever they can be found, giving elevation as recorded on same, and their elevation above or below rail on main track at station op-

posite. In case of large fills or deep cuts, give top of bank or bottom of slope. This will facilitate the projection of future track extension. Where print of yard map is used in making re-survey, show with check mark all stations found correct so that the office may know that nothing has been overlooked. Note corrections and additions plainly and check your notes carefully before returning to the office.

Note.—Notify the office promptly of any changes of any nature in buildings, tracks, etc., in order that the maps may at all times show the yards exactly as they exist on the ground.

If you have any notations to make on blueprints, use black India ink where possible.

PRESERVATION OF TIMBER.

PROF. F. H. BASS.

The demand for timber for construction in the United States is enormously beyond the capacity of the country to yield an adequate supply. The rapidly decreasing forest areas bear ample testimony to this fact.

One remedy for this condition is a scientific management of forest areas. The United States Department of Agriculture maintains a Bureau of Forestry which has made a beginning in this direction.

Another means of lessening the inroads on the timber resources is that of prolonging the period of usefulness of the timber after it is cut, by preservative processes. It is with these processes that this paper has to deal.

The structure of wood is cellular, multitudes of small cells in rows, constituting the fibres. The cell walls and their incrusted covering are composed of organic matter containing carbon, hydrogen and oxygen. These cells are filled with sap which, in addition to the above named elements contains nitrogen. It is this nitrogenized substance which furnishes the chief food for the subsistence of the parastic growths which cause the decay or rot of wood.

The decay of wood was, until the eighteenth century, accounted for by the "Phlogiston" theory and later by Liebig's fermentation theory which assumed that decay was a slow combustion needing only moist air for its progress. It assumed that the fungus, molds, bacteria present were the results of decay. Pasteur, the great French scientist, proved that decay (fermentation) was due to the presence of these parasitic organisms and was caused by their activity.

This theory being accepted, it is evident that if the pores of the wood can be filled and kept filled by a germicide that will not injure the fibres of the wood itself the wood can be preserved indefinitely. Furthermore, the preservative itself must be proof against decomposition. The conditions also require that the preservative be easily injected and capable of penetrating to all parts of the timber. It must be insoluble in water and non-

volatile at ordinary temperatures. The cost of the material and labor of application must be reasonable.

The various processes in use are:

1. Creosoting, using heavy oil of coal-tar.
2. Burnettizing, using zinc chloride.
3. Kyanizing, using bichloride of mercury.
4. Wellhouse, using zinc chloride, glue and tannin.
5. Allardyce, using zinc chloride and "creosote."
6. Boucherizing, using copper sulphate.
7. Thilmany, using copper sulphate followed by barium chloride.
8. Hasselman, using copper sulphate, iron and aluminum.
9. Creo-Resinate, using creosote, resin, formaldehyde and lime.
10. Hazen, using zinc chloride and gypsum.
11. Woodiline, using surface application of substance containing creosote.
12. Vulcanizing.

Numbers 1 and 2 are most extensively used and number 4 is used to some extent in this country. Number 9 is also used in treating paving blocks.

Burnettizing consists in impregnating the wood with zinc chloride dissolved in water. The wood is thoroughly dried after this treatment in order to expel the water and leave the salt in place. Any later exposure of wood treated by this process will surely allow the zinc chloride to be dissolved and washed out. Burnettizing has been largely used for railroad ties, especially by roads in the Southern States. European railroads, after experience with this process, have largely abandoned it.

The process which is most extensively used and which gives the greatest promise is creosoting. Creosote proper is obtained from wood-tar; but the "creosote" ordinarily mentioned in this connection is obtained by the destructive distillation of coal. It occurs chiefly as a by-product of gas-works.

The gases obtained by heating coal in closed retorts, when condensed, give coal-tar and "gas liquor." These upon being run off into a receptacle, separate as the coal tar is the heavier. Coal tar was formerly looked upon as a useless and obnoxious by-product, but is now a most important commercial product.

The coal-tar is subjected to fractional distillation. Up to 170° C. naphtha or light oil is obtained. Between 170° and 230° C. Carbolic oil or middle oil is obtained, and between 230° C. and 270° C. heavy-oil or creosote is obtained. Above 270° C. anthracene is distilled.

Creosote as ordinarily used contains substances which vaporize

both below 230° C. and above 270° C. These are included in the following constituents of creosote:

Napthalenes	190° C. to 270° C.
Anthracenes	290° C. to 305° C.
Phenanthrene	340° C.
Retene	350° C.
Pyradines	116° C. to 251° C.
Quinolines	240° C. to 360° C.

Of these, napthalenes constitute a large proportion of creosote and are of much value as antiseptics. Napthalene proper melts at 80° C. It volatilizes at 218° C. and hence is non-volatile at ordinary temperatures. It is also insoluble in cold and nearly insoluble in hot water.

The process of treatment consists of three divisions:

First. Seasoning.

Second. Subjection to vacuum.

Third. Impregnation with oil.

All three divisions are carried on successively in the same closed receptacle. The seasoning may be either natural or artificial. The usual method, the artificial or accellerated seasoning may be performed by treatment with hot air or with steam. The steam heat liquifies the sap and driving it out by expansion converts it into steam and removes it. Albumens are at the same time solidified. In order that the steaming may be at the same time efficacious and not injurious, specifications for wood preserving usually fix minimum and maximum temperatures, and also the length of time for exposure to these conditions.

The subjection to vacuum follows immediately upon the steaming and completes the process of emptying the pores of the wood.

The third and final stage consists of forcing the creosote into the wood. Specifications fix the amount of oil by weight per cubic foot of wood treated. The temperature of the oil and the pressure at which it is applied are also regulated.

The following specifications for creosoting have been adopted by the United States Government and by the Bell Telephone Company:

I. "The wood shall be impregnated with genuine dead-oil of coal tar."

II. "The lumber shall first be subjected to treatment by live steam in a closed cylinder. The duration of this treatment shall be from 3 to 6 hours, according to the condition of the wood. The temperature shall not be less than 200° F. and not more than 275° F."

III. "As soon as the steaming process has been completed, the steam shall be blown off and the vacuum immediately applied. The pumping shall continue as long as is necessary to remove all sa yand water from the wood and until at least 24 inches of vacuum is obtained."

IV. "Immediately after the exhaustion process and before the vacuum pump has been stopped, the cylinder shall be filled with the oil. The oil shall have a temperature between 125° F. and 250° F. when applied. Pressure shall be applied until 12 lbs. of oil per cu. ft. shall have been forced into the wood."

V. "The oil used shall have a specific gravity of not less than 1.01 at 35° C. and it shall be liquid at 38° C. It shall contain at least 40% of napthalene. It shall contain not more than 4% of water. At least 20% of the oil shall not distill below 270° C.

VI. "Full facilities for inspection of oil or any part of the process shall be provided by the company doing the work."

The following are abstracted from specifications used by the Norfolk, Va., Creosoting Company:

I. "The steaming shall continue from 5 to 7 hours under pressure from 35 to 55 lbs. per sq. in. The temperature shall be not more than 270° F. unless the wood is water-soaked, when 285° F. may be used for the first half of the process. At the end of the process, the liquid shall be drawn off from the bottom of the tank.

"The vacuum shall be immediately applied and shall be not less than 20 ins. It shall continue for from 5 to 8 hours. The temperature shall be from 100° to 130° F.

"The oil shall be dead oil of coal tar containing not more than 1½% of water and not more than 5% of tar and not more than 5% carbolic acid. It must not flash below 185° F. nor burn below 200° F. and shall be fluid at 118° F. It must begin to distill at 320° F. and must yield between that point and 410° F. of all substances, less than 20% by volume Between 410° F. and 470° F. the yield of napthalene shall be not less than 40% nor more than 60% by volume. At 2° above its liquifying point it must have a specific gravity of not more than 1.05 nor less than 1.015."

The following specifications were prepared by Mr. G. C. Wilson for the Twin City Rapid Transit Co., and by his courtesy the writer is permitted to use them:

Twin City R. T. Co.'s Specifications.

The treatment shall be carried on in an iron cylinder in which the ties shall be placed and seasoned by the direct application of live steam admitted to the cylinder. The steam gauge pressure

in the cylinder shall be brought to 20 lbs. and shall continue for 8 or 10 hours. During the process of steaming the cylinder must be frequently drained by a valve located at its lowest point.

At the end of the steaming period a vacuum shall be created in the cylinder, the temperature being maintained above the boiling point. The vacuum must continue until the guage shows a reading of 22 to 25 ins. This reading must be maintained for about 6 hours.

After the material has been thoroughly seasoned, the oil shall be admitted at a temperature of not less than 120° F., which shall be raised to not less than 180° F. under a pressure of not less than 125 lbs. per sq. in. This pressure shall be maintained until the measurement as established shows that the wood has absorbed the required amount of oil (8 lbs. per cu. ft.). The timber may then be removed and piled for shipment.

The oil to be used shall be that obtained exclusively by the distillation of coal-tar, and may contain not to exceed 2½% of water without allowance therefor. Any larger percentage of water contained in the oil shall be allowed for in figuring the quantity absorbed. No oil shall be used that contains over 8% of water.

The sp. gr. shall not be less than 1,0025 at 35° C. (95° F.). It shall be fluid at 38° C. (100° F.), and at this temperature there shall be no substance in suspension. It must not yield more than 20% of its weight by distillation up to:

410° F.	Between 410° F.	and 455° F.
210° C.	210° C.	235° C.

there shall distill off at least 40°. At least 25° shall be what is known as "dead oil" that does not distill under a temperature of 260° C. (500° F.).

Treatment under inspection. Company to furnish samples for test. Access to records of company pertaining to T. C. R. T. work.

The largest creosoting plant in the Northwest is situated at Sandstone, Minnesota. Its capacity is from 30,000 to 50,000 ft. B. M. of timber per day, the amount depending upon the seasoning required. There are shown a plan and sectional elevations and two photographs of the works. The plant shown is at present being enlarged so as to double its capacity.

In the foreground in Fig. 2, is shown the distillery. It is possible to take the coal-tar oil from gas-works and here obtain any desired oil for treatment. Oil having been received is stored in the large tanks shown on the left. From these tanks it is pumped into the creosoting cylinder, a view of the open end of which is

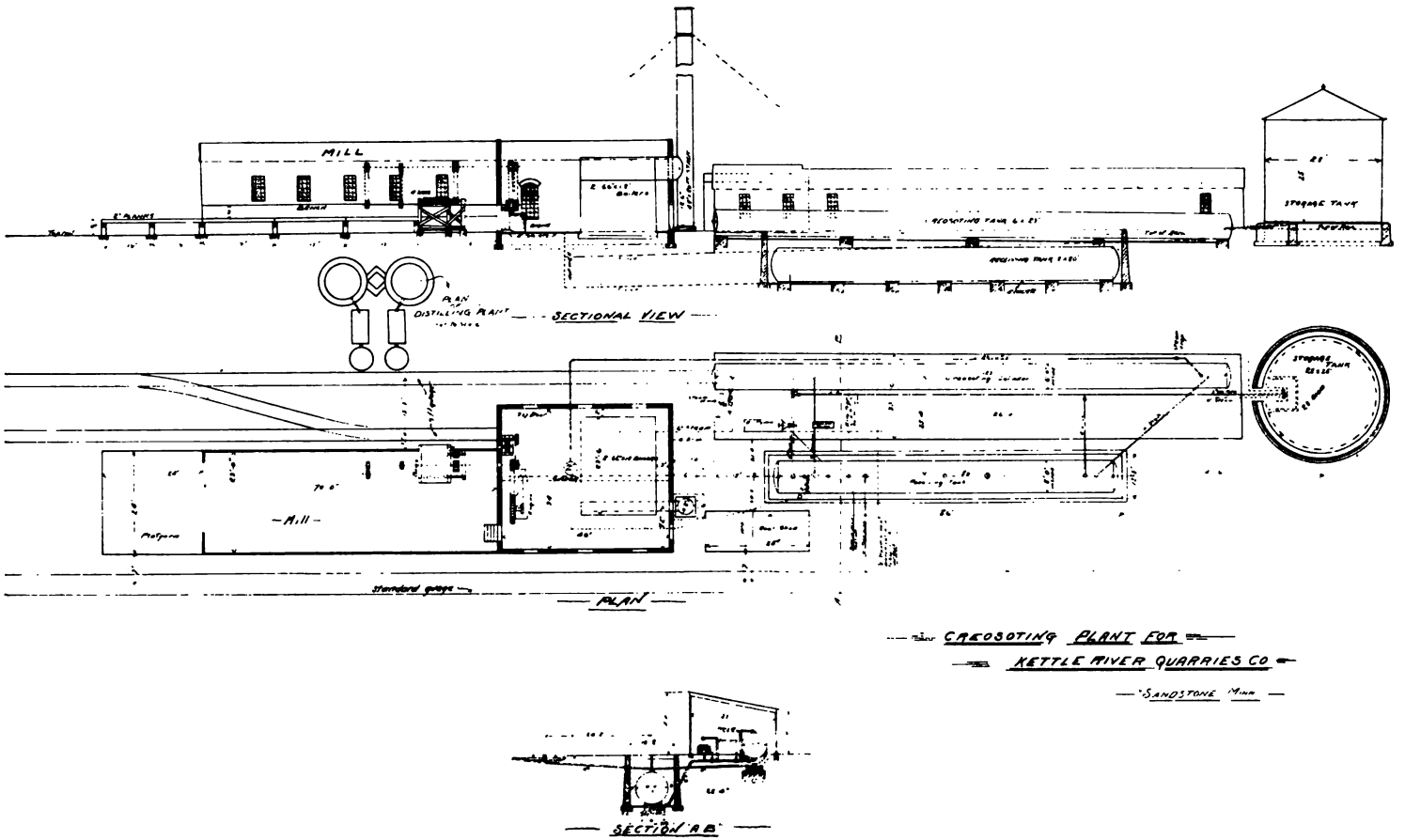

MILL
STORAGE TANK
PLAN
DISTILLING PLANT
SECTIONAL VIEW
Mill
Standard gage
PLAN
CREOSOTING PLANT FOR
KETTLE RIVER QUARRIES CO
SANDSTONE MINN
SECTION A B

Fig. 1.

shown in Fig. 3. There is also shown in this photograph a loaded "cage" or car ready to be run into the cylinder upon the tracks, which extend throughout its length. Upon the completion of the treatment the oil runs by gravity to the receiving tank, whence it is pumped to the storage tank. The creosoting tank is the main

Fig. 2.

feature of the works, as it is within it that the entire treatment is carried on. It must receive careful attention—the location of the steam and drain pipes is important. It must be carefully calibrated so that its exact contents can be known for any elevation of the liquid within and for this means the operator can determine the amount of liquid absorbed by the timber, whose volume is known.

The cost of creosoting varies with the kind of timber to be treated and with its condition. The cost of the creosote is about 7c per gallon, and the cost of creosoting about 5c per cu. ft. of timber treated. In general, the cost will be from 1c to 1½c per lb. of creosote in place.

A first-class railroad tie at Sandstone is worth 50c, and it costs about 50c to creosote it. The life of the tie untreated is about 8 years, treated, it will last 3 or more times as long.

Burnettezing costs about 14c per tie, hence its popularity.

About 2% of the railroads of the United States use the creosoting process. The Louisville & Nashville Railroad is the largest

user; this railroad has pile trestles in use today in good condition built on creosoted piles in 1876. These piles would have lasted 7 years, untreated against decay or only 6 months against the teredo.

At the present time there are about 50 creosoting plants in the

Fig. 3.

United States. About twice as much timber is treated by the zinc chloride process, which, however, is being rapidly superseded by the more effective creosoting.

For evident reasons the industry of wood preservation is sure to expand to great proportions and also to modify and improve its present practice.

The writer wishes to express his appreciation of the courtesies extended by those who have furnished data used in preparing this article and especially to Mr. Buehler, of the Kettle River Quarries Co.

LABORATORY TESTS FOR ROAD METALS.

WM. R. HOAG, C. E.
Professor of Civil Engineering.

Perhaps in no field of engineering activity has the old adage relative to the "Proof of the Pudding" held a more undisputed sway than in the matter of selecting the most suitable materials for road construction.

Nearly all materials which enter into engineering construction today are being subjected to certain physical and chemical tests which leave little doubt as to their suitability and behavior in the actual structure. This is true only in part with material commonly used in our streets and highways. During the past ten years, however, laboratory methods have been devised which are doing much to place this large class of engineering work on a firm scientific basis.

Though every people, since the early Romans, that have figured prominently in the world's history have displayed considerable constructive ability in road construction and have left a few examples of great highways their work was clumsy, costly and showed nothing higher than mere imitative art. The Romans had no conception of a smooth, solid road surface except as made of large, heavy flag-stones, made in nature's laboratory and stored in her hills and their only test of its suitability for such service was by actual trial in road use. Indeed, up to the time of Napoleon, highway construction can be said to have been carried on only as a blind art. Tresaguet (1764), an engineer upon whom Napoleon placed the charge of providing France with a comprehensive system of military roads, is believed to be the first to discover and make use of the one great basic principle in stone-surfaced highways, viz., the re-cementing property of finely divided rock.

For nearly a hundred years after the discovery of this basic principle of stone-road construction the only test of the value of a road metal was its actual trial on a piece of road for a period of years.

Until road construction was removed from under the cloud of blind art and brought into the light of experimental science, little or no progress was made.

True, such engineers as Macadam and Telford did much to

stimulate the work of highway building and became very expert in their ability to judge whether an untried stone would prove valuable in road construction or not. But this was largely personal experience and could not be reduced to rules nor imparted to others.

A series of very elaborate field-service tests on Macadam road was begun in France in 1865 and continued to 1893. These tests were to determine the actual wearing qualities of the different kinds of stone used on the road. Observations were taken at nearly half a million cross-sections of important highways, covering 22,000 miles of road to show how much wear had been caused by a known amount of traffic, determined by a careful census. A full account of this great road material test was published in the report of the Minister of Public Works of France and has been very helpful in selecting the best material from among those available for any locality. However, such field tests are necessarily very expensive and must extend over a period nearly, if not quite, to the average life of the surface metal. The most serious difficulty with such tests is in recognizing and giving due weight to a wide range of attendant conditions outside of the road metal itself, such as condition of foundation as to stability and moisture, climate, winds, traffic, surface, and sub-drainage. etc. The service test was largely valuable in showing a wide range of value of different rocks previously supposed to be equally suitable for road purposes. With these facts science had a foundation on which to build.

A series of somewhat primitive laboratory tests were conducted along with these service tests and by their agreement with the latter encouraged their further development. This was inaugurated a scientific plan for determining by laboratory methods the comparative value of different materials used in highway construction.

First Machines for Testing Road Metal.

In 1878 the French Commission of National Roads decided to establish a road testing laboratory for the purpose of applying certain mechanical tests to road metal, and exhibited at the 1878 Paris Exposition, what is believed to be, the first specially designed machine for this purpose.

This was called the Deval machine, after the name of the inventor, and was clearly but a modification and adaptation of the common rattler used to clean and polish small casting. As early as 1850 certain compression tests were made on small cubes to determine their road building value. These, however, discovered very little of value and were abandoned.

Though good stone roads abound throughout England and continental Europe, yet outside of France and Portugal, very little has been done to reduce their construction to a science.

In this country the situation seems quite reversed. While we have comparatively little Macadam road, we have a half dozen well-equipped road laboratories. The one established by the Massachusetts Highway Commission in connection with the Lawrence Scientific School of Harvard University in 1893 was the first systematic attempt to prosecute, experimentally, studies related all material entering road and street construction. Since then laboratories devoted to this line of investigation exclusively have been established by the Maryland Geological Survey, by Columbia University, Wisconsin Geological Survey, Cornell University, University of California, United States Department of Agriculture, and last, though we hope not to be least, one is now being equipped at the University of Minnesota.

A road laboratory, such as it is proposed to install here should be equipped:

First.—To make all mechanical and chemical tests which may be helpful to road builders in choosing the best of all available material.

Second.—To conduct researches looking to the development of new materials and processes useful in roadbuilding.

A very important part, also, of this laboratory work would be systematic experimentation to determine new and reliable tests for standard as well as new material, also the collection of such data as would be useful to roadbuilders in making specifications for road work.

Road builders recognize three distinct causes that lead to the destruction of road surfaces.

First.—Mechanical agencies, such as the pounding action of horses' feet and the grinding action of wheels. The action of wind and water in removing loose binding material from the road surface might also be classed among the mechanical forces.

Second.—Chemical agencies, such as those whose action results in the decomposition of wood-block and asphalt pavements. The various gases of the atmosphere in connection with the aqueous vapor exert a great influence of a chemical nature on all pavements.

Third.—Physical agencies, such as freezing and then other extreme of temperature, excessive heat, might be termed a separate agency since it has quite a different effect upon the road material from that of freezing.

The action of the last two classes of agents is more or less obscure and no successful attempt has yet been made to imitate them in laboratory tests.

The beneficial effect of water in the recementation action of a stone road is well established though to what extent it is a physical action or a chemical action is a matter of speculation.

Mr. Logan W. Page, Chief of the Road Material Laboratory at Washington, has developed methods of chemical analysis leading to the identification and classification of road materials.

These chemical analyses, besides being useful in connection with the petrographic examination of rocks for classification, furnish, in many cases, valuable information relative to their probable work as a road metal.

The chemical composition of clays, marls, etc., is important and a proper part of the work of a road material laboratory since they enter largely into the manufacture of bricks, cements, drain pipes, etc. The recent practice of using a mixture of burnt and raw clay for a road surface when no stone is available, is adding importance to this branch of the work.

We now return to the consideration of the first and most important class of agencies, viz., the mechanical.

As the life of any particular pavement or road surface is largely determined by the nature and amount of traffic to which it is subjected and as this action is practically altogether mechanical, it is this class which lends itself most readily to profitable study and investigation in the laboratory. We not only seek here to crowd into a brief time the action upon a pavement or road surface but also to unlock the secrets of the individual elements or component parts entering into their structure. Without attempting to treat fully or logically the various mechanical tests which have come into general use, the limits of such an article preclude that—I shall briefly describe the more important machines, their plan of operation and discuss the value of the results in guiding to the selection of the best material.

The Deval Machine.

The Deval machine consists, essentially of a hollow, iron cylinder, so mounted that its axis is at an angle of 30° with the axis of rotation. These cylinders are 20 c.m. in diameter, 34 c.m. in depth, are coupled in pairs and frequently in fours, to multiply their capacity. The charge for each cylinder consists of five kilograms of rocks broken to a size to pass a 6 c.m. ring. The tight fitting cover is bolted on and the cylinder is made to revolve at the rate of 2000 revolutions per hour for five hours. The contents is then removed and all that which passes a 0.16 c.m. mesh sieve is weighed and becomes the argument of the test.

Since only the best varieties show as small a loss as 20 gr. per kilogram this has been adopted as a standard of excellence

and the part of 20 which 20 is of the amount lost by any variety will express the "coefficient of wear."

The following expresses it algebraically:

$$\text{Coef. of wear} = 20 \times \frac{20}{W} = \frac{400}{W}$$

in which W is the weight of the detritus in grains per kilogram of the rock.

While the results obtained by this machine do not always guide to the best selection of a rock for any locality, yet they are of inestimable value to practical road builders.

It is believed that considerable additional information would be furnished, especially as to the recementing power of the rock if this debitus were made with briquetts and tested under tension as in the ordinary test of cement.

The Test for Hardness.

This test is made with what is called the Dorry Machine. This consists essentially of a cast iron disk rotating in a horizontal plane. Upon its upper surface is placed the specimen to be tested. A sand in the presence of water is the abrading material.

A full set of standard conditions are imposed—such as pressure between specimen and disc; quantity and quality of sand; rate of rotation and total number of revolutions.

The loss of material to the specimen after each 1,000 rotations of the disc is determined and the total, after 4,000 rotations becomes the argument for judging the specimen.

This test has not yet been fully developed and some experimentation must be done to assure its ultimate usefulness.

There are other machines designed for special work which are important for the full investigation of road material—such as the Ball Will for preparing rock dust use in the cementation test, Briquette machine for use in making standard briquettes and Impact machine for determining toughness, but the limits of this article forbid more than their mere mention.

Tests for Paving Brick.

The very great favor into which brick has come of late as a paver for city streets has resulted in a vast amount of experimentation looking to a scientific, simple and reliable series of tests for this product. The National Brick Manufacturers' Association has been foremost in advancing this work and after thorough investigation has decided that the earliest tests applied to brick, viz.: Absorption, specific gravity, freezing, compression and extension tests—are of comparative little value and recommends the rattler test as practically sufficient for determin-

ing the relative value of different kinds of paving brick. It is not to be understood that the other tests are of no value for each in the absence of the rattler test may furnish valuable information relative to the new material. For instance, the compression test will reveal very much of value concerning the general strength of a brick and the absorption test will show to what extent vitrification has taken place, i. e., the degree to which the clay particles have united with the silica and water in forming the new chemical compounds. In fact, any one of them will usually furnish enough evidence for the rejection of unsuitable material.

This, while valuable, is far from sufficient. We must not only be able to identify and reject material which, on account of some special weakness, is unfit for use, but we must be able with reasonable certainty, to designate the best for the use to which it is to be put with full regard to cost and availability. The rattler test enables us to do this without the aid of the other tests to such a degree of certainty that no evidence of the minor tests would change the result.

The Brick Testing Machines.

Starting with an ordinary foundry rattler this machine has passed through successive stages until it now consists of a short over-hung cylinder on the inside of which the bricks are clamped. The bricks thus form the lining to the cylinder and are acted upon on their edges alone by the cast-iron shot within.

The standard charge consists of 60 lbs. of 2⅜-in. cubes and 90 lbs. of 1½-in. cubes, the machine is made to revolve 3,000 times at the rate of 40 per minute. The intention with this latest form of the rattler is to subject the bricks to the same action, as nearly as possible, as they get in actual service in the pavement.

The results thus far gained by this machine,—somewhat limited yet,—show a very close agreement with service tests.

Since our brick pavements are kept wet by frequent sprinkling it has occurred to the writer that our mere feature of similarity to actual service would be gained by conducting this test in the presence of water instead of dry, as now practiced. In a series of tests of paving brick which the writer conducted for the Engineering Department of the City of Minneapolis in 1902, a small stream of water was introduced with the rattler with this end in view.

The results showed a marked difference for the same kind of brick between "wet" and "dry" tests, and justify the belief that when properly conducted the "wet" test will prove the more trustworthy test.

PRODUCER GAS POWER.

By Julius Wile.
Rochester, N. Y.

The use of producer gas for power is now being widely adopted in the United States, following the lead set by European countries, especially Germany and England, where it is rapidly taking place of the steam engine. It should be noted that at present this power is more extensively adopted where the problem of heating does not occur, or where it is treated as a separate problem, so that the use of producer gas power is mostly found in municipal electric light, central station and pumping plants, and in factories where the power factor predominates the heating factor. In general the advance in producer gas power is due to the introduction of the suction gas producer, and the producer gas engine. The latter is the development of the gasoline and illuminating gas engines, but it should not be taken for granted that such engines are suitable for producer gas. The producer gas engine operates under a higher compression, and also, as the volume of producer gas, on account of its lower heat value, being in the ratio of 130 B. T. U. to 700 B. T. U. per cu. ft., is about five times that of the higher value gas, it necessitates that the ports and valves of the engine be made larger than would otherwise be employed. Many errors have been made in this country by builders endeavoring to use their standard patterns in making producer gas engines, and the best practice today is to design an engine especially for producer gas.

The reason for the popularity of producer gas can best be shown by the following table:

Efficiencies of Steam Engine and Boilers.

Coal Taken at 13,000 B. T. U. per Pound.

TYPE	Pounds of Coal per B. H. P.	Thermal Efficiency per cent.
Simple non-condensing, throttling	6	3.26
Simple non-condensing, automatic	4½	4.35
Simple non-condensing, Corlis	3½	5.6
Compound non-condensing, Corliss	3	6.55
Compound condensing, Corliss	2¼	8.75
Steam turbine condensing, Corliss	1½	13.
Triple condensing, Corliss	1 1-3	14.75

It will be seen that the ordinary engine usually employed has a thermal efficiency of about 3¼% to 6½%, while the highest type of steam engine, using superheated steam, is about 15%. The following are results compared to steam that have already been obtained:

Efficiencies of Gas Engines and Suction Gas Plants.

Brake Horse Power	Type of Engine and Fuel	B. T. U. per Pound	Fuel Consumption	Thermal Efficiency
20	National; single cylinder, anthracite	15,138	.797	21¼%
90	Crossley; single cylinder, coke	12,411	.91	22½%
250	Duetz; double acting, anthracite	14,600	.744	23 1-3%
300	Crossley; 2-cylinder, anthracite	11,370	.975	24 %

It will be seen by the above that in the Suction Gas Plant in as small size as 20 H.P. an efficiency of over 20% has been effected, while in the larger sizes of 300 H.P., as high as 24% has been accomplished. The tendency is even toward better results.

There are two types of gas producers: (1) Suction Gas Producers, and (2) Pressure Gas Producers.

Suction gas producers are those which get their draught from the engine itself, which effect is automatic in principle; the greater the load the greater the draught and the amount of gas manufactured.

Regular pressure gas plants are those in which the gas is stored in a gas holder and is under pressure, and the draught

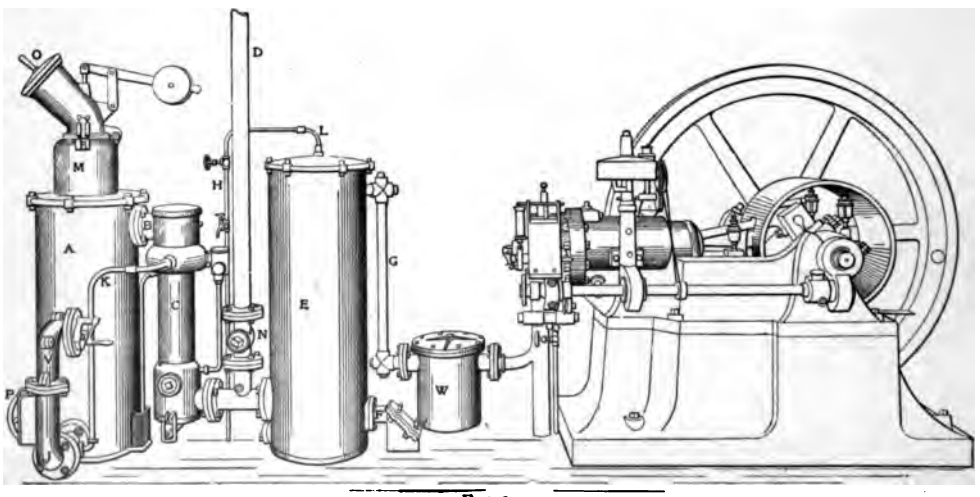


Fig. 1

is created by a steam injector. The steam is furnished by an independent steam boiler.

A typical suction producer plant is illustrated in Fig. 1. It consists of a vertical cylindrical generator A, with the usual double shutter charging hopper, a vaporizer C, and a scrubber E. The gas is drawn off at each stroke of the engine by pipe B, and, passing through the tubes of the evaporator, is drawn through the scrubber E, leaving this at the top and going to the engine. The hot gases impart their heat to the cooling water in the evaporator, and the resulting vapor, together with the necessary air, is drawn under the grate of the producer and through the fuel, making the producer gas.

Suction gas plants are today in actual use in units of from 5 to 500 H.P,. and are limited to the use of anthracite coal or fuels having no tarry vapors, although there is no reason why special generators and scrubbers which eliminate the impurities in bituminous coal and other fuels should not come into use, and experiments are being made with that end in view. Suction plants are limited in their application to plants where power alone is wanted, as there being no storage space of large amount for the gas and no pressure, gas could not be taken off for heating purposes, as is often required where power is used. A glance at Fig. 1 will show that no gas holder is used nor an independent boiler, as the suction of the engine regulates the supply according to the demand, and the necessary steam is raised in the vaporizer by the gases from the generator on their way to the scrubber. Small space is consequently occupied, the plant is economical in first cost and for power purposes using anthracite coal or coke, it is an excellent type; its chief limitation at present being that it cannot make gas for heating purposes, and that it uses the carbonized fuels only, such as anthracite coal, coke or charcoal. An important advantage of the suction type is that, as no injurious gases can arise from it, it can be placed in basements of buildings and other confined spaces with impunity.

Another reason for the popularity of the suction gas producer as compared with the pressure plant, is the fact that while the steam boiler requires constant attention of a man to watch the gauge glass and also feed the coal, the suction producer needs to be fed but three times a day at full load, and twice a day at half load. The attention of a 100 H.P. suction gas producer can be given in about an hour and a half per day, and includes about 20 minutes starting up in the morning, feeding the coal three times a day and cleaning about a half-hour at night. The fire will remain for days without going out in the

producer with a small loss of coal in the producer. This is accomplished by leaving the purge pipe open to the atmosphere so that the generator is subject to a slight draft.

The weakness of the suction gas power at present is its application to anthracite coal, coke or charcoal, and these fuels are only cheap in certain parts of America. Lignite can be used in gas producers where special scrubbing device is introduced to take care of the volatile matter and the tar in it.

It is very probable that there wil be considerable development in the near future with suction producers suitable for using bituminous coal or lignite, and also development in which producer gas will be used for heating.

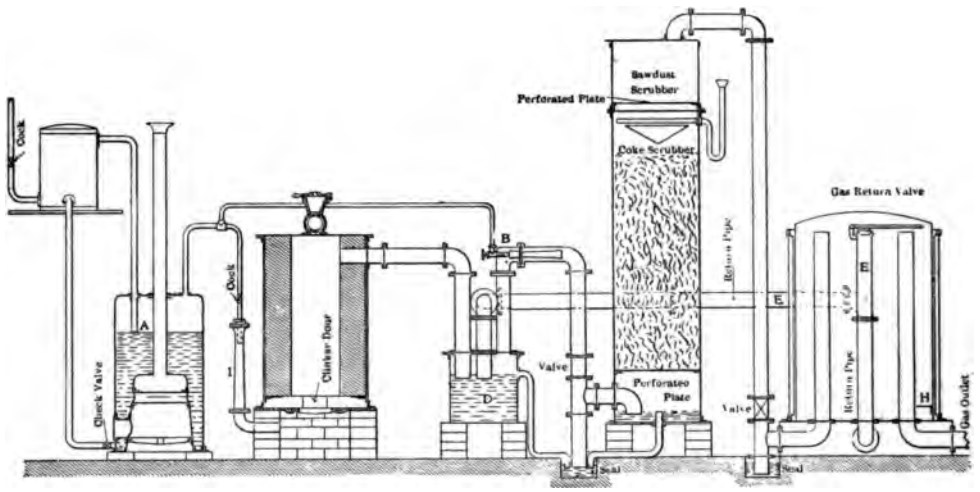


Fig. 2.

A typical pressure plant is shown in Fig. 2, which shows the steam boiler and gas holder. The steam is used to make the gas in the generator and to force it into the holder. Where soft coal is used, the tar in the volatile matter is washed out in special scrubbing devices, which are static scrubbers in some cases and rotary scrubbers in others.

Other gas producers of the pressure type have a double generator in which the tar is decomposed and is used to enrich the gas instead of being washed out.

Pressure plants due to the extra steam necessary, the power to operate fans and scrubbers, operate under about 25% less efficiency than do suction plants. These plants, however, burn soft coal, lignite, or any class of fuel, and are best suited for units of 200 H.P. and upwards. Where the cost of fuel is high, and where uncarbonized fuel only is available, they will find wide application.

DESIGN OF A LONG REINFORCED CONCRETE GIRDER.

FRANK H. CONSTANT, C. E.,
Professor of Structural Engineering, University of Minnesota.

The roof of the new H. W. Wilson building is supported over the ball room by two 60 ft. reinforced concrete girders. On account of the unusual dimensions and weight of these girders some description of the method of computation employed may be of general interest.

Fig. I gives the elevation of one of the girders and shows the position of the reinforcing rods as well as the spacing of the vertical bars.

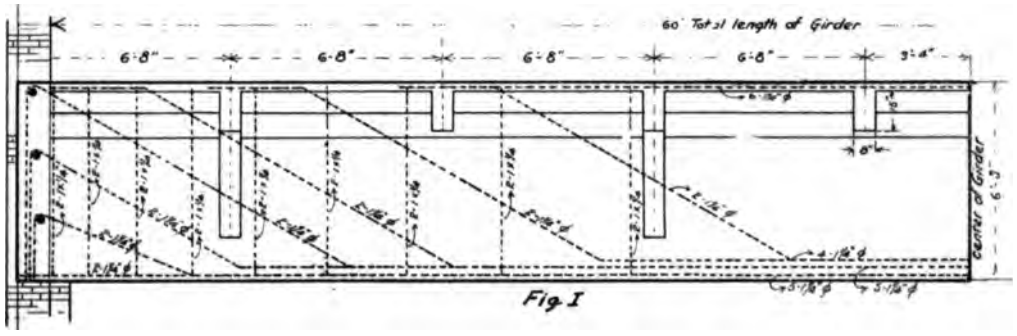


Fig. I

Fig. II is a section taken through the girder near the center and shows the relative positions of the cross beams and roof slab. There are 8 cross beams 21′ 8″ long, center to center of girders, on each side dividing the girders into nine panels 6′ 8″ each. Each alternate beam was joined to the girder by a reinforced knee bracket extending down to about a foot of the bottom of the girder, as shown in the figure, thus giving considerable lateral suport to the girder at four intermediate points of its length. For simplicity the loading upon the girder was taken as being uniform. The girders were proportioned to carry a snow load of 30 lbs. per sq. ft. of roof surface, together with their own weight and such part of the cross beam and slab weights properly belonging to them. The concrete, which was composed of 1 part cement, 2 parts sand, 2 parts gravel and 2

parts broken stone in the upper part of the girder, and of 1 part cement, 1 and ½ parts sand and 3 parts broken stone in the lower part of the girder, was assumed to weigh 140 lbs. per cu. ft., which is slightly excessive. The assumed loading upon each girder was then found to be as follows:

Slab, cross beams and snow	1,750 lbs. per lin. ft.
Girder	1,300 lbs. per lin. ft.
Total	3,050 lbs. per lin. ft.

It is to be noted that the girder itself weighs 75% as much as all the other loading and as its weight increases very rapidly

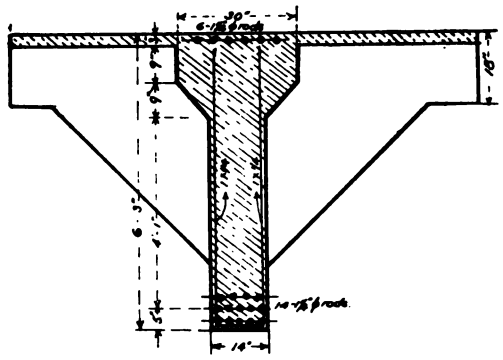


Fig. II

with the length of span it is obvious that this form of construction is not economical for very long spans. In fact, 60 ft. is about the present maximum length in practical construction. It is probable that a steel girder or truss would have been a little cheaper in this case, but the concrete harmonized with the other details of the building, justifying its employment.

The earlier design contemplated a girder of rectangular cross section with both top and bottom reinforcement. But it was at once found that a girder of the width and depth shown could not be designed sufficiently strong. Increasing the width over 14 in. (and proportionately the amount of steel), increased the load to be carried almost as fast as the moment of resistance of the girder, while the maximum depth was limited to about 6 ft. by the height of the building, and the encroachment of the girders into the ball room below. In general a rectangular cross section is uneconomical for all but the shortest spans for the same reason that a steel plate girder or I-beam is stronger than a rectangular beam of same depth containing the same amount of steel, namely, because the effective depth of the former is greater

than for the latter. A little evolution led to the design of Fig. II, and the top reinforcement was retained, partly to strengthen the more distant parts of the top flange and partly to increase the moment of resistance. It is not advisable, on economic grounds, to put much metal in the top flange, since not more than from 1-3 to ½ of the safe working strength of the steel can be developed. It is quite proper to consider a small portion of the adjoining slabs as constituting part of the top flange, the amount depending upon the safe shearing strength of concrete and the designer's judgment as to the buckling strength of the slab in compression and the ability of concrete to transmit stress to points remote from the axis of the beam.

To Find the Moment of Resistance at the Center of the Girder.

For convenience of computation imagine the section above the neutral axis divided into the rectangular and triangular areas a_1, a_2, a_3, a_4. (See Fig. III.)

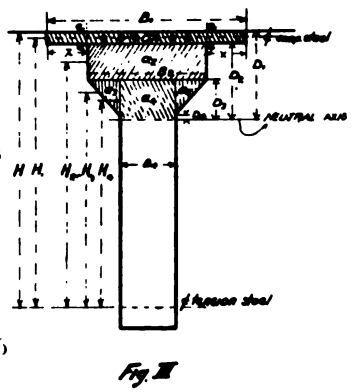


Fig. III

Let B_1= width of a_1= 50″

B_2= width of a_2= 30″

B_4= width of a_4= 14″

D_1, D_2, D_3, D_4=vertical distances shown from neutral axis such that

D_1-D_2=vertical height of a_1=3″

D_2-D_3=vertical height of a_2=9″

D_3-D_4=vertical height of a_3=9″

D_3 =vertical height of a_4

A_1=area of steel in top flange=7.36 sq. in.

A_2=area of steel in bottom flange=17.2 sq. in.

p=per cent of bottom steel to area of concrete above center of steel=1.33%.

$r=\frac{Es}{Ec}=12$=ratio of coefficients of elasticity of steel and concrete. This eratio will generally vary between 10 and 15, according to the proportions of the concrete.

c= stress per sq. in. in top steel.

t= stress per sq. in. in bottom steel.

k_1= stress per sq. in. in top fibre of concrete.

k=stress per sq. in. in any strata of concrete at a vertical distance y above the neutral axis.

H_1=vertical distance from center of bottom steel to center of gravity of a_1=68.5″

H_2=vertical distance from center of bottom steel to center of gravity of a_2=62.5″

H_3=vertical distance from center of bottom steel to center of gravity of a_3=55″

H_4=vertical distance from center of bottom steel to center of gravity of a_4.

H=vertical distance from center of bottom steel to top of beam=70″

Adopting the straight line law of distribution of stress over the compression area.* $k=\frac{k_1 y}{D_1}$. and the total compressions in the several areas are

$$\text{Compression in } a_1 = \frac{k_1}{D_1} \cdot \frac{a_1(D_1+D_2)}{2} \qquad (1)$$

$$\text{Compression in } a_2 = \frac{k_1}{D_1} \cdot \frac{a_2(D_2+D_3)}{2} \qquad (2)$$

$$\text{Compression in } a_3 = \frac{k_1}{D_1} \cdot \frac{(B_2 - B_4)\ (2D_3^2 - D_3D_4 - D_4^2)}{6} \qquad (3)$$

NOTE 1—The compression in the triangles a_3 is found as follows: Let x = width of any horizontal strip distant y from the central axis, and let k=unit stress in this strip. Then total required stress is

$$\text{Stress in } a_3 = \int_{D_4}^{D_3} k x dy = \frac{k_1}{D_1} \int_{D_4}^{D_3} y x dy.$$

$$\text{But } x = \frac{(y - D_4)}{D_3 - D_4} \cdot (B_2 - B_4)$$

$$\text{Stress in } a_3 = \frac{k_1\ (B_2 - B_4)}{D_1\ (D_3 - D_4)} \int_{D_4}^{D_3} (y^2 - yD_4)\ dy$$

$$\text{whence, stress in } a_3 = \frac{k_1}{D_1} \cdot \frac{(B_2 - B_4)\ (2D_3^2 - D_3D_4 - D_4^2)}{6}.$$

---

*Paper by the author "Flexure of Reinforced Concrete Beams in the Light of Recent Research," Engineer's Year Book, 1905.

$$\text{Compression in } a_4 = \frac{k_1}{D_1}\,\frac{a_4 D_3}{2} \tag{4}$$

$$\text{Compression in } A_1 = \frac{k_1}{D_1}\,\frac{rA_1\,(D_1 + D_2)}{2} \tag{5}$$

$$\text{Also tension in } A_2 = -\frac{k_1}{D_1}.\ rA_2.\ (H\text{-}D_1) \tag{6}$$

Summing up total stresses on the section, putting in values of a_1, a_2, a_4, and equating zero,

$$\frac{k_1}{D_1}\left\{\frac{B_1\,(D_1^2 - D_2^2)}{2} + \frac{B_2(D_2^2 - D_3^2)}{2} + \frac{(B_2 - B_4)\,(2D_3^2 - D_3 D_4 - D_4^2)}{6} + \frac{B_4 D_3^2}{2} + \frac{rA_1\,(D_1 + D_2)}{2} - rA_2\,(H - D_1)\right\} = 0 \tag{7}$$

Substitiuting $D_2 = D_1 - 3''$: $D_3 = D_1 - 12''$: $D_4 = D_1 - 21''$ and the numerical values for all other terms, it is found that

$$\frac{50 \times 3\,(2D_1 - 3)}{2} + \frac{30 \times 9\,(2D_1 - 15)}{2} + \frac{16\,(27D_1 - 405)}{6} + \frac{14\,(D_1 - 12)^2}{2} + \frac{12 \times 7.36\,(2D_1 - 3)}{2} - 12 \times 17.2\,(70 - D_1) = 0$$

whence $D_1 = 22.2''$

It is thus found that $D_4 = 1.2''$ and $H_4 = 52.9''$.

If, for the very good concrete used in these girders we let

$k_1 = 650$ lbs. per square inch, then

$$c = \frac{k_1}{D_1}.\ \frac{r(D_1 + D_2)}{2} = 7260 \text{ lbs.} \tag{8}$$

$$t = \frac{k_1}{D_1}.\ r(H - D_1) = 16300 \text{ lbs.} \tag{9}$$

Since 17000 was the maximum safe working strength chosen for the steel, it is apparent that the economical percentage of steel has been used. The low value for c emphasizes the statement made above of the doubtful economy of using steel in the compression flange.

It now remains to find the moment of resistance of the girder for the values of k_1, c, and t just given or determined. For this purpose we must solve equations (1) to (5) inclusive for the total compressions in the several areas and then assuming each compression to act in the center of gravity of its respective area (except in the case of a_3), we must find the sum of the moments of all of the compressions about the center of the tension steel. This sum is the required moment of resistance. In the case of the triangular areas a_3 there will be no appreciable error in using the center of gravity. The exact center of compression for a_3, measured from the neutral axis is found from the equation.

Vertical distance N.A. to center of pressure of a_3=

$$= D_4 + \frac{\frac{k_1}{D_1}\int_{D_4}^{D_3} y^2 x\,dy}{\frac{k_1}{D_1}\int_{D_4}^{D_3} y\,x\,dy} = 1.2 + 6.96 = 8.16''$$

This is 0.96" higher than the center of gravity. It will be convenient to put the compressions, lever arms, and products into a table. (See Table I).

TABLE I.

	Area in sq. inches.	Average compression per sq. inch.	Total compression.	Distance, center of comp. in area to center of steel.	Moment of comp. about center of steel.
a_1	150	607	91,050	68.5	6,250,000
a_2	270	430	116,000	62.5	7,250,000
a_3	72	212	15,250	55.96	855,000
a_4	143	150	21,450	52.9	1,135,000
A_1	7.36	7,260	53,500	68.5	3,670,000
A_2	17.2	—16,800	—290,000	0.0	0

Total moment = ... 19,160,000 inch lbs.

Bending moment = $\frac{3050 \times 60^2 \times 12}{8}$ = 16,500,000 inch lbs.

Excess strength = ... 2,660,000 inch lbs.

$\frac{16,500,000}{19,160,000} = 86\%$. Hence all stresses will be reduced by this ratio.

$k_1 = 650 \times .86 = 560$ lbs. per sq. inch.
$c = 7260 \times .86 = 6250$ lbs. per sq. inch.
$t = 16800 \times .86 = 14450$ lbs. per sq. inch.

The sums of the plus and minus stresses in the fourth column of the table should balance. The small difference is due to slight inaccuracies in the computations. A pocket slide rule was employed throughout.

To find what part of the slab may be included in the top flange of girder: (See Fig. III.)

Let x = width of slab projection on each side of girder.

Then $2x \times 3'' = 6x$ = area of slab projection included in flange of girder.

From the table the average stress per square inch in the slab at the center of span is 607 lbs. Therefore:

$6x \times 607 = 3642x$ = total stress in slab projecting at center.

If the bending moment in the span increased uniformly from the end to the center by equal increments, as in the case of a beam with a single load at the center, the compression in the slab would also increase by equal increments until the maximum of $3642x$ is reached at the center. Dividing this stress by half the length of span gives the increment of slab compression per unit of length of girder. That is, since half the span length is 360 inches,

Increment of slab compression per lineal inch of girder =

$$\frac{3642x}{360} = 10x \quad \text{(nearly)}$$

This increment of slab stress causes a shear in the vertical longitudinal sections, *cc* (See Fig. III) where the slabs meet the top flange. Let q = intensity of this shear per square inch. Since the slabs are 3" thick,

$$10x = 3q \qquad (10)$$

If $x = 10''$, as was assumed, $q = 33\ 1/3$ lbs. per sq. inch. Since the actual loading upon the span was uniformly distributed, instead of being concentrated at the center, the moment increased in proportion to the ordinates of a parabola and the moment increment in the slab is twice as great at the end as in the case just considered, gradually decreasing to zero at the center. Equation (10) may therefore be considered as giving the average shearing stress, the maximum being twice as large. If $x = 10''$, max. $q = 66\ 2/3$ lbs. per sq. inch. This is sufficiently safe, but again applying our safety factor of 86% we get q=57 1/3 lbs., which is a low value for shearing stress in concrete. While the calculations thus indicate that we may consider 10" of slab on each side of girder to form part of the flanges, practical judgment would limit the allowable distance x to this amount, or even less, inasmuch as it is

doubtful if the flange stress will actually reach the extreme end of x, at least in its full theoretical intensity. The excess moment of resistance of this girder indicates that the slab projections need not have been used in the calculations.

To find the intensity of shearing stress in any part of the girder:

It is well known that many concrete beams, reinforced only by straight bars of steel fail first by the opening of cracks beginning near the end of the beam when the shear is greatest and extending from the lower edge upwardly in a diagonal direction towards the center of the beam. These are erroneously called shear cracks but in reality are due to the internal tension generated in the concrete by the longitudinal and transverse shearing stresses. To determine the magnitude of such tension it is first necessary to study the shearing forces.

If we consider a small prism at any point in the beam, it is well known that there are two planes at right angles, viz., the vertical and horizontal planes, in which the stresses acting upon the prism are shears only, and these shears are of equal intensity. Also that there are two other planes at right asgles is which the stresses, called principle stresses, are a direct pull and a direct compression respectively. The principal stresses are generally usequal and their direction with the horizon varies with the distance of the prism considered rrom the neutral axis.

To find the intensity of shearing stress in any plane above the neutral axis, imagine the beam divided by two vertical planes, AB and CD, whose distance apart is dx. (Fig. IV.)

Let C_1 = resultant compression against the part of section AB between A and E;

C_2 = resultant compression against the part of section AB between E and N;

C = resultant compression against AB between A and N = total compression in section.

h_1 = distance between C_1 and center of tension steel.

h_2 = distance between C_2 and center of tension steel.

h = distance between C and center of tension steel.

These resultant compressions are readily found by the use of columns four and five of Table I.

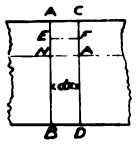


Fig IV

q = intensity of shearing stress in EF;

q_n = intensity of shearing stress in NA;

S = total shear in section AB;

M = total moment in section AB;

b = width of beam at EF.

$$C = C_1 + C_2 \qquad (11)$$

$$M = C_1 h_1 + C_2 h_2 \qquad (12)$$

whence $dC = dC_1 + dC_2$ (13)

$$dM = h_1 dC_1 + h_2 dC_2 \quad (14)$$

When the differentials stand for the change in the several quantities between the sections AB and CD.

Combining (13) and (14) and remembering that $dC = \frac{dM}{h}$, there results.

$$dC_1 = \frac{dM}{h} \cdot \frac{h - h_2}{h_1 - h_2} \quad (15)$$

Also, since $dM = S dx$

$$dC_1 = \frac{S dx}{h} \cdot \frac{h - h_2}{h_1 - h_2}$$

Dividing the total change in C_1 by the area of EF

$$q = \frac{dC_1}{b dx} = \frac{S}{hb} \cdot \frac{h - h_2}{h_1 - h_2}$$

q is a maximum at the neutral axis where

$$h_2 = o,\ h_1 = h, \text{ and } b = B_4$$

$$\text{whence } q_o = \frac{S}{B_4 h} \quad (17)$$

If the concrete below the neutral axis is not stressed in tension the shear in each horizontal plane is constant and equal to q_0 in intensity until the tension steel is reached, while $q_0 B_4$ is the total shear in the entire width of the beam for each lineal inch of length. If p is the perimeter of one of the lower rods, n the number of rods, and a the adhesive stress per square inch, of concrete to steel,

$$a = \frac{q_o B_4}{np} \quad (18)$$

If B is the net width of concrete in the plane of the upper layer of tension rods, and q is the intensity of longitudinal shear in this plane

$$q = \frac{q_o B_4}{B} \quad (19)$$

which determines the greatest number of rods that may be placed in this plane. Since less shear is transmitted to the second and third layers, more rods can be placed in each subsequent layer.

If the concrete below the neutral axis is assumed to take some longitudinal tension, less tension is transmitted to the rods and the

value of the shearing stress slowly decreases below the neutral axis until the steel is reached. Both a and q in (18) and (19) will therefore be smaller.

Returning to the computations for the sixty foot girder we need only to consider the internal stresses below the neutral axis. h is found by dividing the moment of resistance by the resultant compression above the neutral axis and is assumed to be constant throughout the length of the girder:

$$h = \frac{19{,}160{,}000}{297{,}000} = 64.5''$$

Table II gives values of the intensity of shear q_0 taken as a constant below the ventral axis for sections at every ten feet along the girder.

To find the principal stresses p_1 and p_2 at any point of the girder and the angles they make with the horizon:

Let k = direct longitudinal stress in any layer of the beam, plus for compression, minus for tension;
q = longitudinal or vertical shear at the same point;
p_1 = principal stress which is compression, and the larger above the neutral axis;
p_2 = principal stress which is tension, and the larger below the neutral axis;
i_1 = angle which p_1 makes with the horizon at any point;
i_2 = angle which p_2 makes with the horizon at any point.

From Rankin's Applied Mechanics, p. 341:

$$p_1 = \sqrt{\left\{ \frac{k^2}{4} + q^2 \right\}} + \frac{k}{2} \qquad (20)$$

$$-p_2 = \sqrt{\left\{ \frac{k^2}{4} + q^2 \right\}} - \frac{k}{2} \qquad (21)$$

$$\tan 2i = \frac{2q}{k}; \qquad (22)$$

$$\tan i_1 = -\frac{p_2}{q}; \qquad (23) \qquad -\tan i_2 = \frac{p_1}{q}; \qquad (24)$$

Our interest centers in the tensile principal stress $-p_2$. At the neutral axis where $k = o$, $p_1 = -p_2 = q_0$; $\tan i_1 = -\tan i_2$ and i_1 and i_2 are each equal to 45°. Above the axis p_1 increases and $-p_2$ decreases as the top of the beam is approached until at the top, where $q = o$, $p_1 = k_1$ and $-p_2 = o$, while $i_1 = o$ and $i_2 =$

90°. At all points of the beam i_1 and i_2 differ by 90°, or in other words, the principal stresses are always perpendicular to each other. Below the neutral axis $-p_2$ increases and p_1 decreases as $-k$ increases. Our attention must therefore be directed to the value of $-k$ in the concrete below the axis. In determining the moment of resistance the tension in the concrete was neglected and the results were evidently on the safe side. But evidently some longitudinal tension does exist in the concrete and its presence increases $-p_2$, the diagonal tension already referred to. $-k$, however, cannot be greater than the ultimate tensile strength of the concrete, about 150 lbs. per sq. inch, for if this stress is exceeded vertical cracks are found beginning at the lower edge and extending towards the neutral axis until the value of $-k$ is too small to cause further rupture. It is quite likely that such cracks, too minute to be visible to the eye, but complete cracks, nevertheless, across which no tension can pass, exist in all reinforced concrete beams when fully loaded. It may be asked why such vertical cracks are not as dangerous as the diagonal cracks. But a little reflection will show that vertical rupture occurs only near the lower edge of the beam which is heavily reinforced by rods and is caused by stress parallel to the steel and which may readily be transmitted and carried by it; while the diagonal crack is caused by one of the principal stresses which is travelling in a diagonal direction towards the neutral axis and thus getting farther away from the influence of the reinforcement. If it causes diagonal rupture in its progress, the beam must fail unless it is provided with suitable diagnoal or vertical reinforcement. Nearly all deep beams, provided with longitudinal reinforcement only, fail in this manner, and it may be adopted as a safe working principle that all but the shallowest of beams, such as floor slabs, should be provided with some kind of vertical reinforcement, preferably placed in an inclined direction to be approximately parallel to the diagonal tension.

Since $-k$ can not be greater than about 150 (depending upon the quality of the concrete), and may be much less than this, it will be a fair approximation to assume it to be 100 lbs. per sq. inch at the plane of the steel when the beam is carrying its full safe load. Its value at other points will be proportioned to their distance from the axis. This assumption has been made in Table II, where the values of p_1, p_2, i_1 and i_2 have been obtained for several sections and at various distances from the neutral axis for the 60′ girders. It should be noted that q really decreases as k increases whereas, in the table, q is considered constant and equal to q_0. p_1 and $-p_2$ are therefore each a letter too large. Correct values for q could readily be found if it were thought worth while.

TABLE II.

Section at	S	q_0	y	k	p_1	$-p_2$	i_1 in °	i_2 in °
End	91,500	101	.....	.....	101	—101	45	45
End	91,500	101	—12	— 25	90	—114	48½	41½
	91,500	101	—24	— 50	79	—129	52	38
	91,500	101	—36	— 75	70	—146	55¼	34¾
	91,500	101	—47.8	—100	62	—162	58¼	31¾
10′ from end	61,000	67.5	.....	.....	67.5	— 67.5	45	45
	61,000	67.5	12	— 25	56	— 80	49	40
	61,000	67.5	—24	— 50	47	— 97	55¼	34¾
	61,000	67.5	—36	— 75	39	—115	59¾	30¼
	61,000	67.5	—47.8	—100	34	—134	63¼	26¾
20′ from end	30,500	33.8	.....	.....	33.8	— 33.8	45	45
	30,500	33.8	—12	— 25	24	— 48	54½	35½
	30,500	33.8	—24	— 50	17	— 67	63¼	26¾
	30,500	33.8	—36	— 75	12	— 88	69¼	20¾
	30,500	33.8	—47.8	—100	10	—110	73	16
At center	.....	.....	.....	.....	.....	.....	90	.....
			—12	— 25	.....	— 25	90	.....
			—24	— 50	.....	— 50	90	.....
			—36	— 75	.....	— 75	90	.....
			—47.8	—100	.....	—100	90	.....

If the safe strength of the concrete in tension be taken at 50 lbs. per sq. inch, a study of the values of $-p_2$ in Table II will lead to the conclusion that web reinforcement is needed for at least the end third of the girder. Without such reinforcement the girders would be on the point of failing, in spite of the excess moment of resistance.

To find the value of the web reinforcement to resist shear:

In the present state of knowledge regarding reinforced concrete beams the exact relation of the steel web reinforcement to the shearing forces is exceedingly indeterminate. In practical work approximate methods of calculation are applied and the shear members are apportioned largely by judgment. Many beams have been built without any reinforcement against diagonal tension and it was not until many tests of large beams showed repeated failure in this manner that this detail of beam designing received any attention.

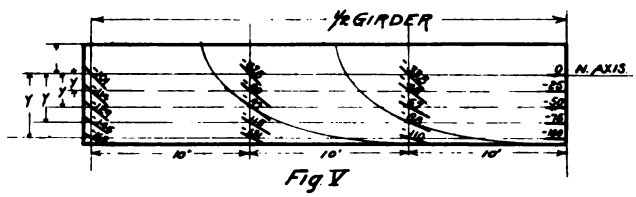


Fig V

In Fig. V the paths of the diagonal tension at the several sections of the girder are shown together with the intensities. One or two full curves are drawn to show the approximate completed path of the stress. The diagonal compressions are at every point perpendicular to these tensions. In the girders under consideration the diagonal bracing was obtained by bending up successive pairs of rods until finally but two horizontal rods were left to run to the end. These diagonals are so spaced near the end that a vertical section will cut at least three pairs. For the

sake of computation they may be considered in a manner similar to the diagonal members of a triple intersection Pratt truss, that is, the shear may be divided equally between the diagonals cut by the vertical section. From Table II the shear at the very end of the girder is found to be 91500 lbs. Since there are six diagonal rods cut by the vertical section the shear going to each rod is $^1/_6 \times 91500 = 15250$. The secant of the angle each rod makes with the vertical is about two. Hence,

Stress per rod $= 15250 \times 2 = 30500$ lbs.

Stress per square inch $= 30500 \div 1.23 + 24800$ lbs. While this is rather high it must be borne in mind that this is for the shear at the extreme end of the girder only and that no allowance was made for the stress the concrete must necessarily take. It shows that below the neutral axis the concrete may be considered more or less as a local medium through which stress passes to go from part to part. Essential it is, of course, for it not only binds the parts together but it is constantly transmitting the compressive principal stresses.

In Fig. I it will be seen that the top ends of the intermediate diagonals are bent and continued horizontally for about three feet. This was for the purpose of creating a sufficient bond between the steel and concrete that the full tensile strength of the rod would be developed. If the safe adhesion be taken at 100 lbs. per sq. inch of perimeter of rod, which allows a factor of safety of about three, the adhesion per lineal inch of rod is about 400 lbs. Then,

$$\text{Length to develop tensile stress in rod} = \frac{30500}{400} = 76''.$$

This requires the full horizontal length at the top and about all of the diagonal length lying above the neutral axis. Inasmuch as the rod begins to lose its tension above the neutral axis the rod may be considered sufficiently banded. At the end of the girder the rods could not be continued horizontally, but instead were bent around short lengths of gas pipe (which acted somewhat as the end pins of a steel truss) and thence down vertically to the bottom of the girder.

The bracing described above has been likened to the diagonals of a Pratt truss.

Fig. I also shows a system of vertical 1"x¼" bars. These may be compared to the verticals of a Howe truss and would in themselves be sufficient to reinforce the girder safely provided they contained enough steel. In this case they are quite light and were put in with the expectation that they will bind the parts together than that they would take any important share of the stress.

The sixty foot girders described above deflected about one-eighth of an inch when the wooden forms and supports were removed, but subsequently showed no further settlement.

EXPERIMENTS ON GAS ENGINE IGNITERS.

PROF. F. W. SPRINGER, E. E.

The following experiments have been used by the writer in an experimental study of ignition apparatus commonly used in gas engines. As the results are to appear in another publication, only the methods of testing, and illustrations will be taken up: They may be classified as follows:—

I. Laboratory tests of touch or contact spark, and jump spark coils, and apparatus.

II. Engine tests.

III. Comparison and service tests of ignition apparatus.

I. Laboratory test of spark coils, batteries, and dynamos:—

a) Determination of the dimensions, sizes of wire, number of core wires, etc.

b) Measurement of the resistance, self induction, capacity of consensers, magnetic flux, hysteresis, and iron losses of spark coils and dynamos.

c) Measurement of the number of vibrations, and igniter lag of jump spark coils.

d) Measurement of the battery energy per spark with touch spark and jump spark igniters at different engine speeds.

e) Measurement of spark energy.

f) Measurement of the maximum secondary voltage, and average secondary current of jump spark coils.

g) Oscillograph tests of spark coils.

h) Battery tests.

i) Igniter dynamo tests.

Number of turns, and resistance of spark coils, etc.

1.—Wheatstone bridge.

2.—Ammeter-voltmeter method.

3.—Kelvin Double Bridge.

1.—The Wheatstone bridge testing set method is especially adapted for measuring high resistance coils.

2.—The ammeter-voltmeter method will be found generally the most accurate and convenient for measuring the resistance of

such spark coils and the primary coils of jump spark apparatus, and the like.

3.—Some form of Kelvin double bridge is the most convenient and accurate means for measuring very low resistance. The standard resistance Rst, Fig. 1, should be as nearly equal as possible, in resistance, and current capacity to the unknown resistance X.

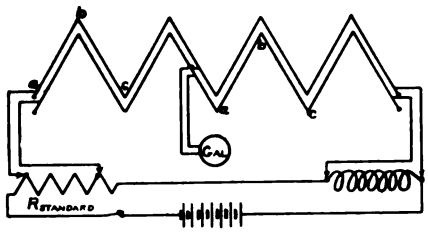


Fig. 1. Kelvin Double Slide Wire Bridge.

Fig. 2. Kelvin Double Bridge and Standard "H" Coil.

Fig. 2 shows a Kelvin double bridge made by winding two high resistance wires on a wooden cylinder. The scheme is shown

diagramatically in Fig. 1, *a b c* constituting one turn on the cylinder.

The Impedance Method will be found very satisfactory for measuring the self-induction in coils containing no iron and fairly satisfactory in coils containing iron with an open magnetic circuit, such as an ordinary type of spark coil. The result will give slightly too large a value of L, by a few per cent, if there is the usual appreciable amount of iron loss in the core.

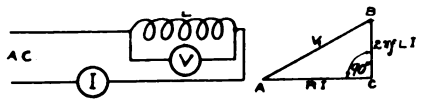


Fig. 3. Voltage Triangle.

In Fig. 3, L is the coil whose self-induction is to be measured. I is an A.C. ammeter or other suitable instrument for measuring alternating currents, such as Siemen's Dynamometer or Kelvin Balance, such that the average current ordinarily taken by the coil will give nearly full scale deflection; V_1 is preferably a static voltmeter, although an ordinary Weston A.C.—D.C. voltmeter, or the like, may be used where the current in the coil is large, as compared to that taken by the voltmeter. The frequency, or the number of cycles per second, of the current may be found thus:

$$f = \frac{\text{R.P.M.} \times \text{number of poles of dyn.}}{2 \times 60}$$

The wave form of the alternator E.M.F. and current should be, preferably, that of a sine curve as shown by an oscillograph record or other wave form test.

Owing to hysteresis and eddy current losses in the iron, the effective resistance of the coil is really larger than will be found by this method so that the value of L, calculated as above, will be too large, probably, by several per cent.

The same method may be used in measuring the self-induction of a high resistance coil, as, for example, the secondary coil of a vibrating, or non-vibrating jump spark coil. The current, however, is very small in most cases and will have to be measured by a very sensitive dynamometer of the galvanometer type, or by means of a low reading electro-static voltmeter connected in parallel with a high resistance non-inductive shunt. In other respects the method is the same as that described above.

The following modification of the above method of measur-

ing the self-induction of such coils will often be found the most convenient.

Connect the apparatus as shown in Fig. 4 using a Weston A.C.-D.C. voltmeter to measure the current. The voltmeter should preferably be of as low a resistance as possible. The data shown in connection with Fig. 4 will illustrate the method applied to a jump spark coil.

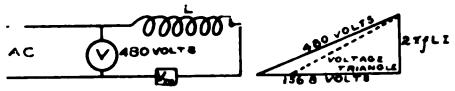


Fig. 4. Measurement of Self-Induction-Impedance Method.

R = 2534 ohms.
f = 63.2 cycles per sec.
VmR = 132.65 ohms.
Vm = 7.81 volts.

$$I = \frac{7.81}{132.65} = .0588 \text{ amps.}$$

$(132.65 + 2534).0588 = 156.8$ volts.

$2 \times 3.1416 f L I = 2 \times 3.1416 \times 63.2 \times .0588 \times I_r$ | $(480 \times 480) - (156.8 \times 156.8)$

$I_r = 1.95$ henries.

Calculation of L.

If the flux of a coil is known, and the number of turns of wire, its self-induction, L, can be calculated.

For example, a certain touch spark coil has 1300 turns, n, of wire, and gives a total flux, ϕ, of 15400 lines of force when a current strength of 0.8 ampere is applied. Then—

$$L = \frac{I}{10^9}$$

$$L = \frac{n\phi}{i} = \frac{10n\phi}{I}$$

$$L = \frac{n\phi}{1 \times 10^8}$$

$$L = \frac{1300 \times 15400}{0.8 \times 10^8} = .25 \text{ henry.}$$

The flux may be measured by a method to be described later.

Where great accuracy is required the three voltmeter method, using a static voltmeter, V, should be used for measuring the self-induction of coils containing iron. This method is described in

detail in Bulletin No. 2 of the Bureau of Standards and is illustrated in Fig. 5.

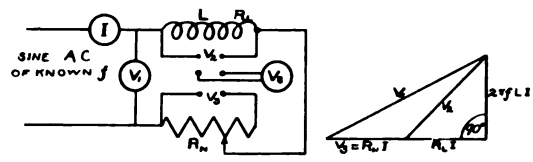


Fig. 5. Measurement of Self-Induction—3 Voltmeter Method.
Note.—Adjust R_N so that $V_2 = V_3$ as nearly as possible.

The self-induction of any circuit may be changed to some other desired value on the following basis:

L varies as the square of the number of turns; hence, if the number of turns be reduced by one-half, L will be one-fourth of the original value, etc.

L varies approximately as the cross-section of the iron core, or as the number of iron wires constituting the core.

L increases with the length of the core; especially when the core is very short, other factors remaining constant. When the length of the core is approximately 20 times the diameter, the resistance of the iron part of the magnetic circuit is practically zero, so that in the case of very long coils, a small change in the length of the core will make no appreciable difference in the self-induction.

Determination of Capacity of Condensers.

1. Calculation from dimensions.
2. By comparison with a standard condenser.

1. $$C = \frac{K\,A\,N}{4\,\pi\,d\,900000}$$

In which C is the capacity in micro-farads. K is the dielectric constant, varying from 2 to 2.3 for paraffined paper, about 6 for common window glass, and 6.6 for mica; A, the area of one side of one sheet of the dielectric which is covered by one side of one condenser plate or sheet of tin foil: N the number of active sheets of dielectric; and d the thickness of the dielectric, expressed in the metric system.

Since the free charge capacity of an induction coil condenser is its useful working capacity, the wiping contact method should be used in comparing the capacity of a condenser with that of a standard.

The method consists simply in charging the condenser by mak-

ing a wiping contact with a set of cells and then immediately, by continuing the motion of the switch or key made in charging, discharge the condenser, by a second wiping contact, through a ballistic galvanometer. Ordinarily the contact should be made for about .01 second.

The deflection of the galvanometer is then compared to a deflection made while using a standard condenser of known capacity and charged with the same set of cells. The capacity of the two condensers being in the ratio of their respective galvanometer deflections.

Measurement of the Magnetic Flux of Cores or Magnets.

AB, Fig. 6, is a coil of fine wire closely wound in a single layer upon a wooden or rubber core 12 or 15 times its diameter in length. Fig. 2 shows such a standard "H" coil, the data of which is: 1773 turns of No. 24 S.C.C. magnet wire, length 118.6 c.m.; diameter, 15.03 c.m.; and flux ϕ per ampere is 3230 lines of force. If the current passing through this coil, as measured by the ammeter, A, is I amperes, the flux passing through the exploring coil E is

$$\phi = \frac{4\pi n\, I\, S}{10} \times K$$

in which S is the cross section of coil AB found by taking as a radius the radius of the core plus the radius of the wire, n is the number of turns of wire per centimeter of length of the coil AB, and K is a correction factor, usually negligible, due to the effect of the coil ends all dimensions being expressed in the metric system.

On breaking the circuit at T, the lines of force, ϕ, will cut the N turns of coil E and cause a deflection of the ballistic galvanometer G. The galvanometer may be shunted to reduce its sensibility and its deflection determined in terms of number of lines of force through coil E, per ampere in coil AB.

A similar deflection should be obtained using the spark coil $A'B'$, and the exploring coil E'. The current I' should be noted. Then if D and D' are respectively the deflections,

$$\phi' = \phi \frac{D'}{D} \times \frac{N}{N'}$$

when the current is I', and N and N' are the respective number of turns in the coils E and E'.

It is desirable to have the resistance of E and E' as nearly equal as possible, and also the deflections of the galvanometer

should be the same as nearly as possible.

If the flux of a magnet is to be measured, simply insert the magnet into coil E', Fig. 6, and jerk it out quickly, obtaining D', the deflection on the galvanometer.

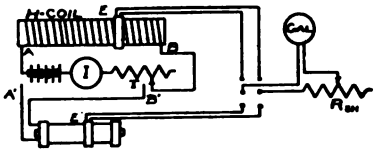


Fig. 6. Measurement of the Magnetic Flux of Cores and Permanent Magnets.

This method is rather difficult to use in case of a magneto-dynamo magnet. The magnet should be placed in its normal position on the pole pieces about the armature, after slipping coil E' over one leg. By jerking the magnet from the pole pieces and out of coil E' a deflection D' will be obtained as above.

The following is the best method to use in obtaining the flux ϕ in the case of a D.C. magneto-dynamo.

$$E = \frac{Z \times \phi \times R.P.S.}{10^8}$$

In which E is the open circuit voltage of the dynamo while running R.P.S. revolutions per second, Z is the number of inductors on the armature core. ϕ is the total useful magnetic flux through the armature.

$$\text{Example, } 25 = \frac{768 \times \phi \times \frac{4800}{60}}{10^8}$$

$$\phi = 40{,}000.$$

In which the magnetic flux through the armature is 40,000 lines of force, the armature having 768 inductors, and giving 25 volts at 4800 R.P.M.

If the self-induction and the number of turns of wire of a coil are known, the number of lines of force may be calculated. As an example, a certain touch spark coil has 1300 turns of wire, its self-induction, L, is .25 henry, to find the flux ϕ when I is .8 ampere;

$$L = \frac{I}{10^9 \cdot} = \frac{N\phi}{10^8 I}; \quad I = \frac{N\phi}{i} = \frac{10N\phi}{I};$$

$$\phi = \frac{L\, I\, 10^8}{N} = \frac{.25 \times .8 \times 10^8}{1300}$$

$\phi = 15400$ lines of force.

The iron loss, including the eddy current loss and hysteresis, can be measured by placing the spark coil core in a suitable solenoid of known resistance, R, and connecting the solenoid in an alternating current circuit as shown in Fig. 7, and the watts, W, and current measured at a known frequency, f, and desired current value I.

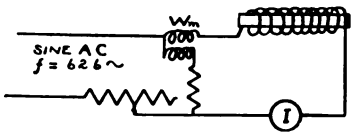


Fig. 7. Measurement of Iron Losses.

$W - I^2 R$ = iron losses.

Coil	Amperes		Watts	Ohms	Watts	Joules	Joules
	I_{ac}	Max I	Wm	R	I^2R	Iron Loss	Iron Loss per cycle
C. F.	1.78	2.52	35 5	8.4	26.7	8.8	.14
C. F.	2.49	3.53	75.4	8 4	53.2	22.2	.36
L. B. F.	1.8	2 55	1.6	.46	1.48	.12	.0019

C. F. is a touch spark coil having about 8 ohms resistance and .25 henry self-induction, and L. B. F. is a vibrating jump spark coil whose primary has about .45 ohm and .0044 henry and a coil of very fine iron wire.

The above tests have only comparative values as they do not equal the iron losses in a spark coil core in actual service. Since the eddy current losses vary as the square of the rate of change of the magnetic flux $\left[\frac{d\phi}{dt}\right]^2$, the eddy current loss will be much greater in service than in a test with a sine wave alternating current.

Measurement of Igniter Lag.

The igniter-lag of any jump spark coil, and the rate of vibration of a vibrating coil, can be easily measured by the apparatus shown in Fig. 8.

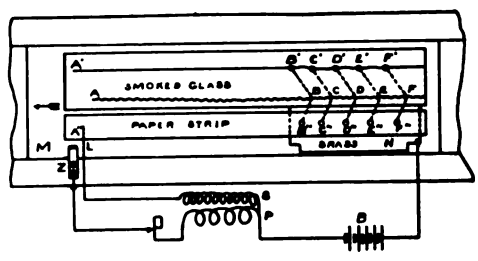


Fig. 8. Measurement of Igniter Lag and Number of Vibrations.

A strip of smoked glass is fastened to a 4"x18" board, M arranged to drop between guides. A tuning fork, of, for example, 128 vibrations per second, is placed so as to make the wavy line AB.

The brass plate, N, and the contact finger, Z, complete the

primary circuit during the latter part of the fall of the board.

One of the secondary coil terminals, *L*, is placed close to the board so that the spark may puncture a strip of paper, placed over the plate at *B″*, *C″*, etc.

The hole *B″* is made by very slowly lowering the board till contact is made between *Z* and *N*. The holes *C″*, *D″*, *E″*, *F″*, are made during the fall of the board. The time *B″ C″* is the igniter lag, and *C″ D″*, *D″ E″*, and *E″ F″*, the time of respective vibrations.

The letters *A*, *A′*, *A″*, etc., mark synchronous points of spark puncture, tuning fork and vibrator records. They are found by laying off *A″ B″*, etc., on *A B*, etc., and *A′ B′*, etc.

The phase relation of the primary and secondary current can be determined experimentally by fastening a stylus to the vibrator of the coil so that it may also trace a line on the smoked glass as shown at *A′ B′* etc.

A method for measuring the number of vibrations without, however, giving any indication of the igniter lag, is to cause the secondary coil to spark at the end of a revolving arm and noting the distances between sparks in terms of the speed of the arm.

The oscillograph method is, however, in all respects the best method for determining the number of vibrations per second, igniter lag, etc.

The subject and method of measuring high insulative voltage such as those of jump spark coils is fully treated by Fisher in the Trans. of the St. Louis El. Congress, Vol. II, p. 296.

The average secondary current of spark coils may be meas-

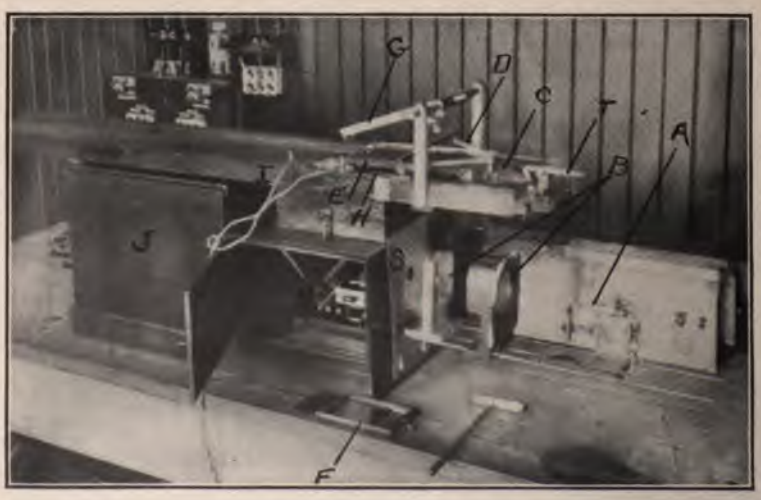


Fig. 9. Oscillograph Apparatus.

ured by introducing a suitable D.C. or A.C. ammeter in the secondary circuit, depending on whether the average value or the square root of the mean square value of current is desired.

The secondary current may be also obtained from oscillograph records by means of an average planimeter.

Oscillograph tests of touch and jump spark coils may be made by such an apparatus as is shown in Fig. 9, the different parts as indicated by letters being: A,—right angle arc lamp; B,—system of lenses for concentrating rays of light on a slit at *S;* C,—slider carrying the plate holder *F*, smoked glass plate, *E*, and the wedge *H*, which closes the circuit at *I* during the flight of the slider; D,—rubber band; T,—trigger; and J,—box containing a double, high frequency type of Duddell oscillograph.

The plate holder, F, has a clamping screw for preventing the plate from sliding. A stylus is fixed to one of the legs of the tuning fork so as to trace a wavy line on the smoked glass plate during its flight, in order to record the time of the curve.

The beams of light from the two little mirrors of the oscillograph are deflected at right angles at N up through a slot to the photographic plate in the slider C, the movements of the light spots are at right angles to the direction of motion of the photographic plate.

The following curves with accompanying data indicate the performance of the apparatus and the results in case of a touch spark coil and a vibrating jump spark coil respectively.

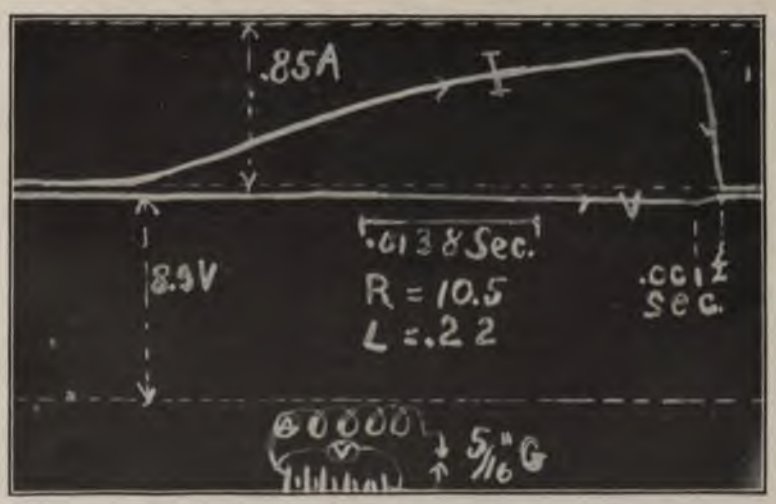


Fig. 10. Oscillograph Record of a Touch Spark Coil.

The curves marked I and V are respectively the current and battery voltage curves of a touch spark coil. The value of the time t, the voltage V, current I and self-induction L, appear on the record.

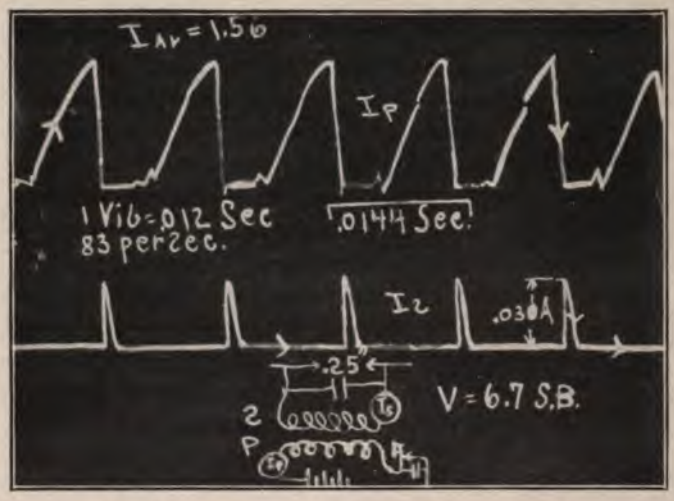


Fig. 11. Oscillograph Record of a Vibrating Jump Spark Coil.

The upper curve, I_p, is that of the primary current, and the lower curve, I_s, the secondary or spark current. The data used are—

Battery voltage	6.37 volts	Vib. per sec.	83
Av. primary current	1.56 amps.	Coulombs per vib.	.019
Av. Watts	10.3	Energy per vib.	.124 Jaulos
Max. primary current	4.8 amps.	Apparent core energy	.051
Time of primary contact	.008 sec.	Spark gap	.25 inch
Time of primary open circuit	.004 sec.		

Period of secondary current (approx) .0014 sec.
Max. secondary current, .03 amps.

Good strong igniting spark.

SPEED VOLTAGE AND CURRENT VOLTAGE TESTS OF IGNITION DYNAMOS

A speed voltage curve is made simply by taking simultaneous readings of the speed of a dynamo and its open circuit voltage at different speeds. A magneto dynamo would give such a curve as that shown in Fig 12.

Measurement of the armature resistance should be made, preferably, by the ammeter-voltmeter method in the case of the direct current machines, on account of the high resistance offered to small currents by the brushes and contacts; otherwise, the Wheatstone Bridge method will be found more convenient.

The current capacity of a dynamo depends upon two factors, i.e., the allowable heat limit of the dynamo, and the demagnetizing action of the armature. The heat limit of a dynamo, or rather the limiting current, is usually determined by running the dynamo at the desired speed, preferably the speed at which the dynamo is to be operated, and allowing it to discharge a measured current during a sufficient time for the armature to reach the maximum allowable temperature.

The rise in temperature can be very accurately determined by

noting the increase in the resistance during the heat run, or by the use of an ordinary thermometer placed upon the armature, and covered with a small pad of cotton.

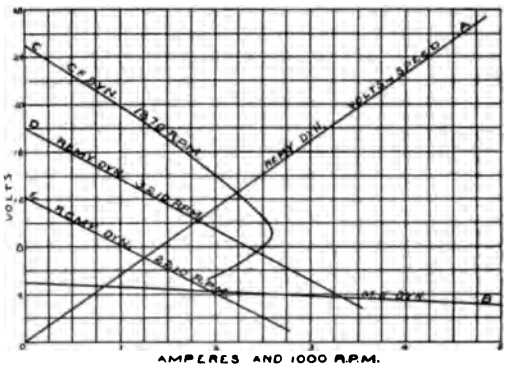


Fig. 12. Curves from Ignition Dynamos.

As most ignition dynamos are used intermittantly, the heat limit is usually not as important in determining the suitability of a dynamo as that of the armature reaction. The latter is found by taking simultaneous readings of the voltage and armature current with different amounts of resistance in the external circuit at any desired speed. The curves shown in Fig. 12, D and E, C and B, are the result of such a test on a Remy type M.V. magneto Miller-Knoblauch constant voltage, and Carlisle-Furch shunt dynamos, respectively.

II.—*Engine Tests*—

The conditions attending the operation of a gas engine are so numerous and complex that unless great care is exercised the engine variations and difficulties will completely mask the results determined from experiments made in order to test spark coils or igniting systems.

The variable conditions which must be considered are three: (1) which include the mechanical adjustment and conditions of the engine; (2) variations in temperature and grade of fuel; (3) variation in the fuel charge due to: (a) the action and adjustment of the automatic carburetor; (b) the throttle opening; (c) engine speed; (d) atmospheric temperature or the temperature of the charge of air when a heater is used; (e) humidity of the air; (f) barometric pressure; (g) back pressure; (h) cylinder temperature; (i) time of the previous explosion, etc.; (4) variations due to the size and time of the igniting spark.

It is evident from the above that before beginning any really serious tests of spark coils in service, a rather complete set of en-

SKILLED OBSERVERS

By J. T. Fanning, C. E.

Partial View:—The remark is sometimes truthfully made of men that: "they do not see more than half of what they look at."

A group of wide-awake men who have witnessed some startling event may individually give quite varied descriptions of the event on a later day because the portions of the accident of which they took cognizance were different. They had not received from the same event the same impressions, probably because they had not trained themselves in observation even to securing full optic impressions.

Such men may be classed as untrained obeservers, and they remain among the manual laborers obliged to develop the muscles of the arm and hand to compete in the manual labor struggle for daily bread.

There is a training that is based upon *seeing* that may be worthy of consideration by those who desire to go up, step by step, into a higher class of occupation.

Training:—When graduates of an engineering class go out from an honored university their several diplomas certify that they are proficient in all the knowledge of the text books of their curriculum and inferrentially that they are skilled in the sciences, literature and art and have had training such as fits them to solve intricate mental problems; hence our quotation relating to partial sight especially as modified by partial mental acumen, may seem inharmonious in a lecture room where students have had much rigorous training, for such is the training which may most aid in the skilled observations such as shall be here suggested.

Whatever the chosen specialty of the student shall be, then the more rigorous his training shall have been and the more extended his experience, the broader and more precise shall be his optical vision and the more acute his mental perception. The untrained observer sees only superficial features of what is open to his vision while the trained observer sees comprehensively, in addition to the general features, individual parts even to the characteristics and properties of minute details, according to his developed capacity.

Structural Work:—Civil engineers have their professional work chiefly in connection with structures of some character, whether it be merely an earth embankment, a culvert, a broad spanning viaduct, a lofty tower, or a locomotive engine that shall speed a train and precious passengers across a continent.

At the present moment we have in especial consideration such skilled observers and workers as are covering our cities and pathways with structures.

The ability to design, invent or create a structure that has a new purpose or that better than before fulfills a purpose comes

erence to the dead center marks on the fly wheel while turning the engine over by hand in the proper direction.

The adjustment of the carburetor should be made according to the directions of the manufacturer, at least at the start.

The temperature, specific gravity and quantity measurements of the fuel while simple enough are quite troublesome. Probably the best way is to take the temperature by means of an ordinary thermometer inserted in the feeding bottle. The latter consists of a plain glass bottle with straight sides, calibrated in c.c.m. or 1/100 of pints, out of which the fuel is siphoned to the carburetor. The bottle should be of such a size that a good reading of fuel consumption can be made during a 2 or 3 minute run.

The specific gravity, weight and volume can be obtained at once by weighing a quantity of the fuel in a bottle of known volume, filled to a mark on the neck of the bottle. This result may then be compared with the weight of the bottle full of water.

Engine speed should be taken with a tachometer or preferably, by means of a calibrated magneto-dynamo or a voltmeter.

Angular velocity variation will not as a rule have any importance so far as ignition is concerned. A test, however, is easily made by smoking the periphery of the fly wheel with a candle and moving a vibrating tuning fork across the face of the fly wheel so that a wavy line may be traced by a stylus in a spiral around the wheel. The tuning fork should be placed in a tangential position to the wheel. Another method is given in the Electrical World, Vol. XLV, No. 15, p. 716, 1905.

There are two common methods of measuring the power output of a gas engine, namely, the prony brake or friction absorption brake and the calibrated dynamo methods. The latter is the best for work requiring accuracy and quickness.

The latter method consists in belting the engine to a dynamo of suitable capacity, preferably separately excited, and measuring the total armature current, Ia, field exciting current If, speed of the armature and voltage, E, at the brushes of the dynamo. The latter is preferably measured by placing the voltmeter leads directly upon the commutator opposite the middle points of the brushes.

Then the horse power of the engine may be calculated as follows:

$$\text{Horse Power} = \frac{IaE + K + If\,Ra + \text{belt loss}}{746}$$

in which K is the watts as measured by the ammeter, Ia, and voltmeter, E, required to run the armature of the dynamo without a belt as a motor at the same speed and with the same field current

as when the readings Ia and E in the above equation were taken. K includes all th constant losses of the dynamo when running as a dynamo or motor.

$I^2a\ R\ a$ is the watt loss in the armature, Ra being the resistance of the armature between the voltmeter terminals, measured at the same temperature as that at which the readings of the H.P. were taken. The belt loss is usually very small.

NOTE.—The Indicator cards here shown were taken from a 4.5"x5" 2 cylinder, 4 cycle, 33% compression, high speed, White Marine Engine, manufactured by the Globe Iron Works, Menominee, Wis.

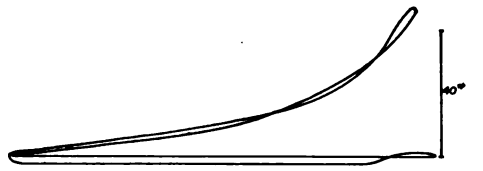


Fig. 13. Compression Card. Throttle wide open.

Fig. 14. Compression Card. Throttle nearly closed.

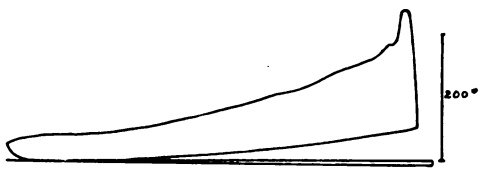


Fig. 15. Explosion Card. Throttle wide open; spark leading sufficiently to obtain the best form of card.

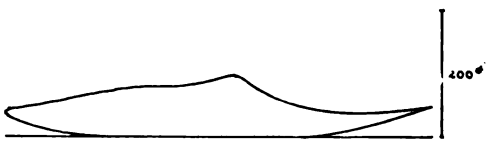


Fig. 16. Explosion Card. Spark too late.

Fig. 17. Explosion Card. Spark too early.

Indicator cards are almost indispensible for close work in ignitor tests. The indicator can be mounted, in case of a jump spark engine, by screwing a tee and nipple in place of the spark plug and mounting the latter, and the indicator in the tee.

Probably the best reducing system for high speed engines, is a miniature cross-head and connecting rod connected directly to the hub of the fly wheel. The construction should be very substantial. The indicator drum cord may be carried over a light sheave directly to the miniature cross-head.

Compression cards such as those shown in Figs. 13 and 14 may be taken, with a weak indicator spring, by throwing off the spark an instant before the indicator throttle is opened. These cards show very accurately the compression pressure, the amount of throttling, i.e., "suction" at different speetds, etc.

Explosion cards, such as Figs. 15, 16, 17, may be used in calculating the indicated horse power under the desired conditions; and by comparing the I H.P. with the out-put H.P. the mechanical efficiency may be calculated, and the engine friction determined. The cards may also be used in determining the time required for ignition, and the character of the explosion, etc.

The exact time of ignition which will give maximum thermal efficiency is a function of the piston speed, cylinder temperature, compression pressure, rate of inflammation, etc., and varies with different engines under different operating conditions. High speed engines usually require ignition, but in general, the greatest thermal efficiency will be obtained when ignition occurs late, i.e., after the crank pin has passed the center, provided, however, that combustion is completed considerably before the piston reaches the end of the stroke.

The thermal efficiency is a maximum at maximum cylinder temperature, or jacket water temperature, maximum compression pressure, and that maximum piston speed at which combustion may be complete in something less than one stroke. Maximum thermal efficiency does not necessarily, or usually, coincide with maximum out-put, while maximum mechanical efficiency usually does.

The point of ignition which will give maximum power is usually earlier than that which will give maximum thermal efficiency, since maximum power is largely dependent upon the speed of the engine up to that speed at which the in-take friction, inertia, of the new charge, back pressure, and insufficient time for complete combustion affects the output.

III.—*Comparison and service tests of different igniters*:

It is very essential in making a comparative test on igniting devices to maintain constant engine conditions. One of the best ways in which to do this is to connect the two sets of coils, batteries, etc., to the two ends, respectively, of a double throw switch, the middle one being connected to the engine. Either igniting set can then be used by simply throwing the switch without stopping the engine or changing any of the conditions, and the difference in the operation of the engine, such as change in speed, power, etc., noted under the desired engine conditions, as for example, with different throttle openings, variable back pressure, different amounts and kinds of fuel, different speeds, loads, etc.

Service tests consist simply in a long time test of an igniter under the varying conditions of service, to determine the reliability, wear, temperature rise, battery demand, etc.

Thanks are due to the Globe Iron Works, of Menominie, Wisconsin, The Gugler Electric Manufacturing Company of Minneapolis, and others for the use of apparatus, and assistance in carrying on the experiments described above.

SKILLED OBSERVERS

By J. T. Fanning, C. E.

Partial View:—The remark is sometimes truthfully made of men that: "they do not see more than half of what they look at."

A group of wide-awake men who have witnessed some startling event may individually give quite varied descriptions of the event on a later day because the portions of the accident of which they took cognizance were different. They had not received from the same event the same impressions, probably because they had not trained themselves in observation even to securing full optic impressions.

Such men may be classed as untrained obeservers, and they remain among the manual laborers obliged to develop the muscles of the arm and hand to compete in the manual labor struggle for daily bread.

There is a training that is based upon *seeing* that may be worthy of consideration by those who desire to go up, step by step, into a higher class of occupation.

Training:—When graduates of an engineering class go out from an honored university their several diplomas certify that they are proficient in all the knowledge of the text books of their curriculum and inferrentially that they are skilled in the sciences, literature and art and have had training such as fits them to solve intricate mental problems; hence our quotation relating to partial sight especially as modified by partial mental acumen, may seem inharmonious in a lecture room where students have had much rigorous training, for such is the training which may most aid in the skilled observations such as shall be here suggested.

Whatever the chosen specialty of the student shall be, then the more rigorous his training shall have been and the more extended his experience, the broader and more precise shall be his optical vision and the more acute his mental perception. The untrained observer sees only superficial features of what is open to his vision while the trained observer sees comprehensively, in addition to the general features, individual parts even to the characteristics and properties of minute details, according to his developed capacity.

Structural Work:—Civil engineers have their professional work chiefly in connection with structures of some character, whether it be merely an earth embankment, a culvert, a broad spanning viaduct, a lofty tower, or a locomotive engine that shall speed a train and precious passengers across a continent.

At the present moment we have in especial consideration such skilled observers and workers as are covering our cities and pathways with structures.

The ability to design, invent or create a structure that has a new purpose or that better than before fulfills a purpose comes

as a sequence to accurate observances of details, to intelligent perceptions of their natures, forms and purposes, in other words to seeing them according to the broadest meaning of seeing things.

The suggestions of the present moment are not offering a short cut to knowledge, such as students might earnestly desire, but they are intended to make the path to eminence firmer and, as well, to supplement the class work in the different branches of mathematics, mechanics, chemistry and geology that enters into structural design.

Precision of observance is only in small part a time consumer, but with the training engendered by ambition for success it comes as a habit and gathers constantly in enhancing volume a most valuable fund of knowledge such as gives power and advantage among fellows and competitors.

Text-book Aid:—After the graduation there will probably come to the graduate consciousness that the four years of higher student work has been indeed short, and he will note that the text books, because of limited time allotted to them, have covered the sciences along general and elementary lines and that the books have presented chiefly foundation theories. These foundation theories are necessities in preparation for practical work and constitute a useful skeleton which is to be filled in with practical details so that the combination may be wrought into actual structures. Insomuch as the class-room acquisitions of knowledge are of general and theoretical character they must be supplemented by knowledge of practical details of structures, and such or similar details, in their several kinds must have been seen accurately and precisely and absorbed mentally before the practitioner is fitted to design new structures.

The design of a structure is the mental creation which, in plan and specification, indicates to the mechanic what the materials of the structure are to be, how the materials are to be formed and how the materials are to be put together. The skillful designer composes an artistic structure in materials as the poet composes in words, grouped into metrical rhymes, or as the musician composes in notes grouped in pleasing intervals and harmonious chords.

But the sctructure in process of erection is wholly a practical creation and the designer must have comprehended its practical features as well as its mental conception.

Preparatory Experience:—Each young structural—or architectural—engineer needs his preparatory field work and he ought to become proficient in preliminary surveys, staking lines and grades, inspections of constructions, and superintendence of constructions but naturally he looks forward to the day when his occupation shall be chiefly in designing structures that, when constructed, shall be eminently useful, but the engineer cannot hope to design structures of merit until he is a master of the minute details of which the perfect whole is composed and the engineer does not become master of all minute details until he has trained himself in methods of observation so as to absorb the purposes, qualities and forms of the respective parts of struc-

tures, and furthermore, he must study and be master of affecting conditions beneath and surrounding his proposed structure.

Detail Drawings:—The designing engineer has a crucial test in the making of detail drawings and preparing the specification of his structure. Herein the anatomy of the design is spread out in full not only before the client but before the contractors who may offer to convert the mental conception into an actual structure at a competitive price.

The contractor and his foreman read at a glance the sum of the designer's accumulated observations, his reflections upon them and the resulting practical skill of the engineer. The foreman and mechanics who shall work to the detail drawings will know at a glance if each respective material specified is the best of all materials for its duty and if the detailed form is that giving to the material its highest efficiency, or if the form of detail is economical as respects work of shop tools and economical as respects transportation to place and erection in place.

The text books have often been prepared by men who were unfamiliar with practical details such as the mechanics comprehend and know by intuition and such books give little aid to the young designer in his early commissions and, if he has not previously trained himself to minute observations of details, as a skilled observer, and to frequent sketching of details and to abosrbing practical knowledge, his weakness may lead to his personal discomfiture as well as his client's distrust and to his mechanics' contempts.

Sketching:—A test of accuracy of an observation of a given structural detail is made by an off-hand sketch of the detail prepared some hours after the observation. Then compare the sketch with the original and note if the contracts, the forms, the proportions and especially if the constructive purposes have all been observed with precision. Such sketches will give a draftsman's facility, but of more value will be the training of the eye to see much of that that is looked at and to see accurately the significance of the detail observed. Such sketching will also give facility of describing by sketches to a client or a mechanic, for the conception of the detail has become sharper through the training that has given facility to the hand to delineate and such sketching will fill the storehouse of the mind with practical suggestions that will be useful in new applications of similar details and in new designs.

Surveys:—The trained observation acquired by frequent accurate sketchings has broader uses than applications to mechanical details; for instance, if a duty of an engineer is to survey a field on which he is to locate a mechanical plant he has not only to make an instrumental and tape-line measure of the shape and a topographical survey of the surface of the site but he must see the geological and meteorlogical conditions of the site, the relations of neighboring buildings and dwellers and the character of approaches, or if he is to locate a new machine enlarging the capacity of an existing mill he must not only measure the available floor space and plan the foundation but he must see every post, beam, belt and pipe that may be in the way of the

placing or operating the new machine. In fact, he must have a complete mental photograph of the situation as well as tape-line measures and levels.

Specialty Merging:—A specialist will take most interest in observing and sketching details and storing mental photographs intimately related to his specialty but when it becomes his duty to design a new structure, or advise a client, or to direct mechanics, he is impressed with the breadth of his specialty and its merger with allied specialties.

If the engineer's work is a new railway there will at least be demand for expert knowledge in several sciences as well as in earth work and masonry of the roadbed, metalurgy of the track, mechanics of the engines, pumps and rolling stock, structural work of the bridges and architecture of the terminal stations.

If the work is an hydro-electric plant there will be included among the several sciences, meteorology, the flow of streams and storage of water, the topography and geology of the watershed and site of the works, the hydraulic engineering of the water power, the architecture of the power station, the mechanical engineering of the turbine equipment and the electrical engineering of the station installation, and the transmission lines with all their multitudinous practical details.

Enlarged Visions:—Through the supplementary training that leads to seeing much of that which is looked at there comes enlarged visions.

We have thus far discussed seeing from the practical side as developed in optical vision and chiefly in absorbing mental photographs of details. There follows naturally an increasing power to see pictures that are creations of the developed brain, to theorize on what is seen and to draw inferences therefrom and to reason on the inferences to a convincing conclusion.

Minnesota Projects:—A theoretical definition of Engineering is the art and science by which the forces of nature are made subservient to man and the mechanical properties of matter are made useful to man in structures and machines; and the engineer is said to be the skilled artist and scientist through whose efforts the above named useful results are accomplished.

The practitioner long in the field has the feeling that the skilled engineer is one who conceives the possibilities of usefulness in the forces of nature and the properties of matter and devises the multitudinous practical details by which, when combined in a whole, the forces of nature and properties of matter are made subservient and useful to man.

Minnesota has some engineering practitioners who have made their mark in their fields and we have goodly reports from them, even from the Isthmus of Panama on the South to the Land of the Lady of Snows on the North.

Minnesota has at home some notable engineering projects that well illustrate theoretical engineering problems and their practical execution and illustrate the merging of several specialists' duties in their varied and numerous details.

St. Anthony Falls Power:—The falls of St. Anthony, on the

Mississippi river, so near these University buildings that in primitive days the campus lands continually received tremor from the tremendous plunge of its waters, was a pioneer in great water powers of the Northwest; and, in fact, was double in magnitude of the notable water powers of New England. It was conspicuously notable as illustrating an engineering conception of a new method of water power construction, and this at the early dates of 1857 to 1860.

At the head of St. Anthony Falls the bed of the river is a stratum of blue Trenton limestone of firm grain and about twelve feet in thickness while beneath this firm stone is a stratum of St. Peter silicious sandstone with its quartz grains cemented in a moderate degree. The St. Peter stone is easily tunneled.

When the whole river was brought under subjugation a dam resting on the limestone rock and about sixteen feet in height, was started a few hundred feet up-stream from the crest of the falls. This dam projected from each shore in arms of about three hundred feet length at right angles to the general direction of the river flow and then both arms extended diagonally about five hundred feet up-stream and met in mid-channel in an acute angle. The two central angle wings formed the flood overfall. The two right-angle arms next the shore formed protection for the mills which were built below them on the limestone river bed.

This combination of geological formation and construction of dam permitted the turbine water wheels to be set in a well-like excavation in the limerock with their discharge draft tubes extending down into the soft St. Peter sandrock. Tunnels were then cut in the sandrock from below the falls back and under the firm limestone to the draft tubes and such tunnels, when lined with masonry or plank to prevent scour, constituted the tail races of the mills. Metallic tubes or pen stocks took the water from the dam into the turbines. Thus 48 feet effective head was secured.

This new method of water power development, admirable for its time, for high-head powers, has since been, in its general features, adopted as the method of developing the high-head water powers of Niagara Falls.

Koochiching Falls Power:—We may allude to another Minnesota water power now being constructed and located on the Rainy river at Koochiching Falls.

The low water flow of the stream when measured was found to be 3,500 cubic feet per second and the natural fall twenty-five feet, which should give 7,936 net continuous horse powers. The falls are located about two miles down-stream from Rainy lake and at low water the fall from the lake to the river surface below is about two feet. Rainy lake has an area of 330 square miles while the water shed above the falls has an area of 16,000 square miles. The natural low flow and fall would give a fine water power, for the minimum flow is fifty percent greater than the minimum flow of the Mississippi river at St. Anthony Falls. The theoretical problem was to make the variable flow more even and thus increase the rate of the minimum power. Instrumental in-

vestigation showed that the natural fluctuations of Rainy lake from flood level to low water level were eight feet and that a dam on the crest of the natural Koochiching fall might flood the river back over the lake and hold the river and lake at flood height so that the stored eight feet of water on this 330 square miles lake area might be drawn as required for enhancing the rate of flow and the power used.

So unusually large a percentage of lake mill-pond storage, when controlled and used with even flow would increase the minimum flow from 3,500 cubic feet to 13,500 cubic feet per second, while the effective fall would be increased from 25 feet to a mean of 30 feet, and the net continuous horse powers would be increased from 7,936 H. P. to 36,733 H. P. This is a resource of nature greatly enhanced and made useful.

St. Louis Falls Power:—Another Minnesota water power now in process of construction presents interesting features of conception and details. It is located on the St. Louis river in the neighborhood of Duluth.

The St. Louis river rapids, from Thomson to St. Louis bay, have a fall of 440 feet, but the minimum flow of the river has been small. These rapids have often been offered in the market for sale in six different mill sites and powers. There seemed to be no demand for the properties. On comprehensive study of the situation it was observed that 370 feet of this fall could, with the aid of about two miles of canal and about one mile length of penstocks be combined into one power with 350 feet net effective head pressure upon the turbines. It was also found that there were excellent opportunities for the construction of large storage lakes upon the St. Louis river watershed, which could be made to conserve the rainfall and greatly increase the minimum rate of river flow. This high head acting on the increased flow would yield 60,000 or more net horse powers in proportion to the number of storage lakes brought into use. This power is being built for a hydro-electric power and its turbine and generator units are of 10,000 electrical horse powers capacity each.

The canal extends along an ancient terrace plain to the head of the penstocks, and is of capacity for the full development of the power. The upper section of the penstocks is of wood-stave pipe having steel bands and each penstock is of seven feet clear internal diameter. These wood-stave tubes are continued down the slope to where the static head of water is about two hundred feet and each penstock has capacity to supply water for one unit of machinery when working at a rate of 12,000 net hydraulic horse powers. Three of these penstocks have been laid for the first installation of turbines and generators and arrangements have been made for laying three more as the demand for power shall increase.

Such wood-stave pipes, banded with metal, are the invention of the speaker and he laid the first, which was of six feet uniform internal diameter, in the year 1873, and *that* wood stave pipe is still in successful use with prospect of many years more of full usefulness after more than thirty years' service.

At the St. Louis river power the remaining length of the penstocks, from 200 feet down to 350 feet head is of plate steel, riveted and proportioned as is first-class boiler work.

Through the aid of electric transmissions and high tension currents this water power may distribute its work as required over an area of territory having one hundred miles radius from the power station.

Wisdom:—Such skilled observations, the seeing of much that is to be seen, lead primarily to a knowledge of the kind of practical constructions in details that have been most approved and have survived in the evolution of mechanical practice, they lead to increasing clearness of perception that must be acquired and shown in the detail drawing and described in the specification and that gives power of facility of description of the details to the client and accurate information to the mechanic. Such skilled observations, persisted in, lead to a fund of precise knowledge that accumulates like compounded interest and that becomes professional capital, precious as rubies and pearls of great price.

The advancement of the young engineer toward high rank in his profession is progressive, hence these suggestions relating to supplementary self training need not be discouraging because of seeing greatly varied details and designs, but rather encouraging for they so broaden out progressively the technical training of the class room as to gradually wrap the young practitioner in a mantle of competency and wisdom.

None of the famed practitioners have flashed like a meteor on the public gaze at or near the day of their graduation. The famed engineers have rather been vigorous self trainers before and after graduation, with worthy ambitions, and have been persistent workers, accumulating practical knowledge, technical skill and mental expertness and developing exalted conceptions of useful works and power of original design and mental creation that have given such engineers final rank among men to whom genius is attributed.

Such skilled observations and mental developments give to the young engineer confidence that his profession is great and noble and that its mechanisms and constructions are conspicuous among worthy accomplishments of men and that the lines of his profession may guide his practical acquirements, his technical skill and his mental conceptions, according to his successive abilities along a brilliant pathway, while at the same time wonderful resources of nature have by him been made subservient to men and valuable properties of matter have by him been made useful to men.

While we cannot all attain to the front rank, the profession offers excellent rewards to those who earnestly seek them. Even the young observer may perceive that notable engineering works are admirable not only as a whole but admirable even to minute details and may perceive that most of the great and fine structures of the world have been executed by engineers, and that such engineering structures are, next to works of the omnipotent Creator, most useful, most observed and most admired by the intelligent men of the great public.